Junner, Norman Ross
The geology and ore-deposits of Walhalla - Wood's Point auriferous belt

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Papers and Discussions.

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THE GEOLOGY AND ORE-DEPOSITS OF THE WALHALLA-WOOD'S POINT AURIFEROUS BELT.

BY N. R. JUNNER, M.C., D.Sc., D.I.C., London (1851 Exhibition Scholar, University of Melbourne, 1913).

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INTRODUCTION.

(*a.*) *General.*—The following thesis is an outcome of an investigation undertaken by the writer, at the suggestion of Professor Skeats, of the dykes and associated auriferous reefs of the Walhalla-Wood's Point belt, with the view of determining what relation, if any, existed between the petrological nature and the extent of metasomatic alteration undergone by the dykes, and the genesis and localization of the gold.

Although the greater part of the writer's time in the field and laboratory was occupied in studying the dykes and auriferous occurrences, a study was also made of the general geology as a basis for the special investigation. In addition, it soon became evident in the field that secondary enrichment had played a marked part in re-concentrating the gold, and some interesting data in this connection have been collected. For example, indubitable evidence has been found of nuggets of gold having been formed by secondary processes.

In the writer's journeyings in the field the excellent topographical and geological maps by Messrs. W. Baragwanath and O. A. L. Whitelaw have been of invaluable assistance. One must travel through the ranges to appreciate fully the difficulties of topography and undergrowth and the lack of comfort under which these gentlemen worked in producing such accurate results.

The completion of this research, which was started in 1912, has been retarded by the writer's absence on military duties during the period September, 1914, to July, 1919.

(*b.*) *Situation.*—The area dealt with in this paper is the belt of country about 12 miles wide extending from Walhalla in the south to Jamieson at the northern end, and includes the one-time important gold-fields of Walhalla, Toombon, Donnelly's Creek, Aberfeldy, Jericho, Matlock, Wood's Point, Gaffney's Creek, Ten-Mile, and Enoch's Point. The total area embraced is about 600 sq. miles.

(*c.*) *History of Gold Mining, &c.*—Most of the gold-fields of this belt were discovered between 1860 and 1864, and mining flourished between these dates and 1875. From this time onwards the usual fluctuating periods of activity and depression were the rule, until at the present day the industry is in a very decadent state.

The largest yields came from the famous Cohen's line of reef at Walhalla. It has been worked to a depth of 3375 ft. vertically, and has yielded approximately 1,478,000 oz. of gold and paid £2,378,290 in dividends, of which total £1,283,400 were paid by the Long Tunnel mine and £788,640 by the Long Tunnel Extended.

Of the other mines in this belt, the largest producers have been the Morning Star, A1, All Nations, New Loch Fyne, and the Rose of Denmark.

Approximate total yields from these mines are given below, viz. :—

Name.	Gold.	Depth.
Morning Star	£1,040,000	0–400 ft.
All Nations	132,000 oz.	0–450 ft.
A1	£500,000	0–1200 ft.
New Loch Fyne ..	100,000 oz.	0–700 ft.
Rose of Denmark ..	50,000 oz.	0–1300 ft.

(*d.*) *Acknowledgments.*—In the foremost place the writer desires to thank Professor Skeats for kindly criticism and advice on many occasions and for granting numerous facilities and much assistance in the University Geology Laboratory.

To Professor W. W. Watts, F.R.S., of the Royal College of Science, London, he is greatly indebted for valuable assistance and for kindly interest in the work.

To the Director of the Geological Survey, Mr. H. Herman, he wishes to record his thanks for granting facilities to see unpublished plans and certain thin sections of rocks from this belt; also for two rock analyses made for him at the Mines Department Laboratory. To his officers, Mr. W. Baragwanath, Mr. O. A. L. Whitelaw, Mr. A. M. Howitt, and Mr. T. W. Dewey, he is grateful for many courtesies and much valuable information.

To Mr. Baragwanath particularly he is indebted for whole-hearted assistance in every possible way.

To Mr. M. O. Copland, Principal of the School of Mines, Ballarat, his thanks are due for helpful advice and for numerous references to the literature.

To the various mine managers of this belt the writer is greatly indebted for the cordial assistance granted him in carrying out his investigations and for the hospitality accorded him on many occasions. In particular, he desires to thank, in this connection, Mr. J. Friel, manager of the New Loch Fyne mine, Matlock; Mr. J. Till, manager of the A1 mine, Gaffney's Creek; Mr. Kenny Smith, manager of the Eldorado mine, Gaffney's Creek; Mr. Hogarth, manager of the Rose of Denmark mine, Gaffney's Creek; and Mr. F. Higgins, of Enoch's Point.

To Messrs. Tallin and Sweeting, of the Geological Department of the Imperial College of Science, London, the writer is grateful for certain rock-sections and microphotographs, and to Mr. Dudley King, of the Melbourne University Geological Department, for numerous rock-sections.

To the Commissioners of the Royal Commission of the Exhibition of 1851, whose Research Scholarship made this investigation possible, the writer is indebted for many kindnesses.

Finally, the writer desires to express his indebtedness to Dr. Summers and Mr. F. A. Singleton, B.Sc., of the Melbourne University, for supervising the editing of this paper during the writer's absence.

PART I.—PHYSIOGRAPHY, GENERAL GEOLOGY, AND PETROLOGY.

1.—PHYSIOGRAPHY.

The region described in this paper is characterized by marked relief—more than 2000 ft. near Wood's Point—and a youthful topography. Narrow valleys deeply indented in the Silurian and Ordovician bed-rocks are the rule.

The divides have a markedly level-topped character, suggesting a one-time plateau now highly dissected. The general slope of this plateau appears to have been to the south, as is evidenced from the following heights of certain Older Basalt and sedimentary residuals :—

Older Basalt Residuals.	ft.	Sedimentary Residuals.	ft.
Mt. Buller	5911	Mt. Timbertop	4500
Connor's Plains	4340	Mt. Terrible	4000
Mt. Useful	4720	Main Divide ..	av. 4000
Aberfeldy ..	app. 3600	Aberfeldy ..	app. 3600
Moondarra, Walhalla	app. 2000	Walhalla (Black Diamond Hill)	2080

The northern limit of this plateau was possibly the Mansfield sunk land of Fenner (No. 15, p. 394).*

The Main Divide pursues a meandrine course in a general east and west direction through the centre of the belt. Its present position appears to have been determined by the greater activity of the north-flowing streams—namely, the Goulburn and Big Rivers—and it probably was at one time much further to the north, as suggested by Dr. Griffith Taylor (No. 47).

Throughout a very close relationship exists between stream-directions and the grain of the country. The following very important rivers which drain this belt—namely, the Goulburn, Thomson, Aberfeldy, and Big Rivers—run parallel to the strike of the Silurian and Ordovician sediments for long distances, and their main tributaries pursue courses at right-angles to the strike.

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* The figures in brackets throughout this paper refer to the list of publications shown on pp. 253-256.

Fig. 1 illustrates in a striking manner this relationship between stream-directions and structural lines, strike, and jointing ("trellis drainage" of Brigham). In general the streams follow closely the anticlinal axes, and the divides and spurs the synclines.

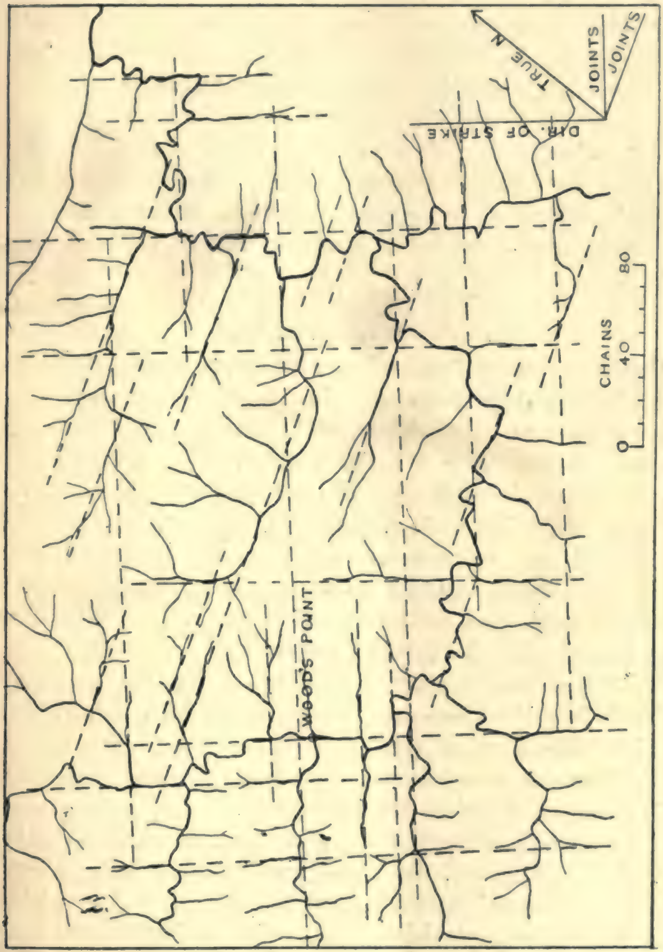


Fig 1.

Trellised Drainage of the Goulburn River near Wood's Point.

Showing relations between stream-directions and the strike and jointings of the Silurian strata.

Remnants of a former river-system are preserved in the form of coarse gravels, sands, and silicified conglomerate beneath residuals of Older Basalt in certain parts of this region. Good examples of these gravels can be seen at numerous places beneath the basalt patches on the divide between the Thomson and Aberfeldy Rivers from Aberfeldy as far north as Beardmore's. There is a southerly fall in the level of these gravels of nearly 500 ft. in the ten miles between these places. They appear to be relics of a stream flowing in a general southerly direction, which was buried by lava-flows from Aberfeldy, where, the writer is informed by W. Baragwanath, the basalt is nearly 1000 ft. thick.

2.—General Geology.

A.—SEDIMENTARY ROCKS.

(1) *General.*—The Walhalla–Wood's Point auriferous belt consists chiefly of a thick series of sediments of Silurian age.

Flanking these rocks on either side in the vicinity of the main divide are beds of Upper Ordovician age.

The relationship between the latter beds and the Silurian strata is not clear. According to E. J. Dunn (No. 12, p. 8), "the junction of the Silurian and Ordovician systems near the Royal Standard mine is very clearly marked with a distinct unconformity." However, no fossils have yet been found in this vicinity to indicate the presence of beds of Upper Ordovician age.

In the Yarra track section, north-west of Matlock, no structural break is evident between the two formations. The Upper Ordovician beds have a similar trend to the Silurian, and, although they are more cleaved, they do not appear to be any more intensely folded than the latter beds.

In the Jordan River section above Jericho, as pointed out by Mr. O. A. L. Whitelaw, the basal gritty sandstones and conglomerate of the Walhalla beds rest directly on the highly fossiliferous Upper Ordovician beds, while further south, near Mount Easton, shales and slates containing Monograptus intervene between these beds.

(2) *Upper Ordovician.*—Strata of this age appear in the cores of domed geanticlines near Mount Easton, Matlock, and the Big

River on the western flank of the belt, and near the Black River on the eastern side. Lithologically, these beds consist for the most part of black and grey thin-bedded slates and shales, with occasional thin bands of soft white and dense black sandstone. Certain loose-textured nodular beds of low specific gravity, with included lapilli of andesitic material, occur on the south-western flank of Mount Easton. They appear to be contemporaneous tuffs.

The Upper Ordovician in places has yielded a rich graptolite fauna. W. Baragwanath's fine collection from the Mount Easton area has been described by the late Dr. T. S. Hall (No. 20, p. 266).

The fauna corresponds closely with that of the Upper Glenkiln and Lower Hartfell beds—close to basal Bala—of the English nomenclature.

(3) *Silurian.*—Beds of Silurian age cover the whole of the central auriferous area of the belt. Their general order of succession is as follows:—

Yeringian (Upper Silurian)	Walhalla beds.
	Panenka beds.
Melbournian (Lower Silurian)	Monograptus beds.
	Black and grey mudstones and sandstones of Thomson and Big Rivers.
	Store Point–Mount Useful beds.

(*a.*) *Walhalla Beds.*—These beds occupy the central geosynclinal area between the eastern and western basal grits shown on the sketch map, Plate I.

They are in the main of shallow-water marine or estuarine origin, as is shown by the abundant ripple-marking, false bedding, mud-cracks, worm and crustacean tracks throughout these beds. Marine fossils are fairly common, and, although plant-remains are numerous, they appear to be of sea or estuarine origin.

The Walhalla beds may be subdivided broadly as follows:—

Upper Shales.
Holy Terror Grit.
Alternating Feldspathic Sandstone and Shale.
Basal Grit and Associated Limestones.

Upper Shales.—Stratigraphically, these are the highest beds of the Silurian series, and are found only in the troughs of the main geosynclinal. For the most part they are very thin bedded, highly cleaved, grey-green shales and slates with a little sandstone. Remains of plants referable to *Haliserites Dechenianus* Göppert, and *Bythotrephis divaricata* Kidston, are found in the basal members of these beds.

Holy Terror Grit.—This term has been applied by Mr. O. A. L. Whitelaw (No. 57, p. 12) to a very persistent band of fossiliferous grit on the eastern side of the main geosynclinal axis. On the western side this feature is not so well defined, and is represented by coarse-grained and gritty sandstones, which are fossiliferous in places.

The Holy Terror grit consists chiefly of rounded grains of quartz normally ⅛ in. to ¼ in. in diameter, with occasional fragments of chert, slate, and sandstone.

Fossils are common, but they are generally in poor state of preservation. Some forms collected by Mr. Baragwanath from this grit in O'Keefe's Gully, near Aberfeldy, were described by Mr. F. Chapman (No. 7, p. 68) as *Atrypa reticularis* Linn. sp., *Orthis* (*Dalmanella*) *testudinaria* Dalman, *Fenestella*, and (?) *Cladopora*.

Alternating Feldspathic Sandstones and Shales.—The shales are thin bedded and grey-green and black in colour for the most part. Occasional thin bands of black carbonaceous shales are interbedded with them. Plant remains, referable to *Haliserites Dechenianus* Göppert, *Bythotrephis divaricata* Kidston, and other indeterminate forms occur in these beds. Yellow, brown, and black sandstones and gritty beds are common near the base of the Walhalla beds. Ripple-marking, false bedding, &c., are common in these beds.

Thin sections of the sandstone show the presence of a considerable amount of detrital igneous debris—plagioclase feldspar, chlorite, leucoxene, and fragments of chert and silicified ash.

Fossils are not uncommon, but in general their specific characters are difficult to determine owing to their poor state of preservation. They consist chiefly of crinoid remains, brachiopods, and corals.

Basal Grit and Associated Limestones.—The basal grit of the Walhalla beds is a well-defined feature traceable on either flank of the main geosynclinal axis from Walhalla to Jamieson. In the vicinity of the Thomson River copper mine this member is represented by a conglomerate made up largely of coarse pebbles of basic igneous rocks—hornblende diabase, variolite, &c.—derived possibly from rocks of Heathcotian age. It also contains pebbles of gneiss, quartz, black chert, quartzite, and sandstone (No. 29, p. 296).

In the northern portion of the belt the basal grit is coarse-grained and very quartzose. One specimen from Enoch's Creek, near Enoch's Point, consists mainly of rounded grains of vitreous quartz with occasional fragments of slate, chert, sandstone, and some igneous material.

Another specimen, from Standers Creek, is composed of grains of sub-angular quartz, chert, silicified ash, plagioclase, biotite flakes, pyrite, and red iron oxide. Muscovite is rare.

Poorly preserved fossils, chiefly crinoid columnars, orthoceras, and corals, are plentiful in the basal grit. *Chonetes cresswelli* Chapman, *Leptæna rhomboidalis* Wilckens sp., *Pleurodictyum megastomum* Dun, have also been described from it.

Lenticular patches of black coral and crinoidal limestone occur intercalated with the basal conglomerate at several points on the Thomson River, north of the copper mine, at the Tyers River, west of Walhalla, and at Deep Creek, on the east side of Walhalla.

These limestones have yielded a rich fauna of Yeringian (Gothlandian) age. The Favositidæ is abundantly represented. *Favosites forbesi* Ed. and Haime, *F. nitida* Chapm. *F. gothlandica* Lam. are common forms. In addition, *Cyathophyllum approximans* Chapm., *Heliolites interstincta* Linn. sp., fragments of *Stromatopora*, are not uncommon. Crinoid columnars, Trilobite remains, and *Girvanella* also occur in these limestones.

Chemically, the limestones consist chiefly of $CaCO_3$, as the following analyses show:—

	1 %	2 %	3 %
$CaCO_3$	92.83	96.20	93.50
$MgCO_3$ ..	0.65	trace	—
$FeCO_3$	1.23	1.25	1.47
SiO_2	3.84	1.70	4.00
H_2O	n.d.	—	0.70
Fe_2O_3	0.69	—	—
Al_2O_3	0.98	—	—
Total ..	100.22	99.15	99.67

1.—Black limestone, Cooper's Creek, near the Thomson River copper mine. Analyst, N. R. Junner.

2 and 3.—Tyers River limestone (*vide* Progres Report, Victorian Geol. Survey, 1876).

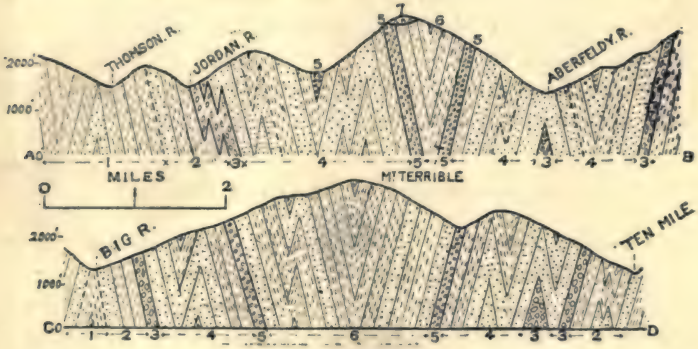
(*b*) *Panenka Beds.*—These beds are best developed between the Jordan River and Yarra track. They consist chiefly of soft yellow fossiliferous mudstones and shales. They underlie the basal grit of the Walhalla beds, and apparently overlie directly the Upper Ordovician strata.

The following are some of the fossils collected from these beds by Mr. O. A. L. Whitelaw:—*Panenka gippslandica* M'Coy sp., *Tentaculites matlockiensis* Chapman, *Styliola fissurella* J. Hall, var. *multistriata* Chapm., *Cycloceras tenuiannulatum* M'Coy, var. *australis* Chapm., *Ceratiocaris* sp., *Paracardium*, and *Pleurotomaria* (No. 8, p. 226).

(*c*) *Monograptus Beds.*—Beds containing abundant Monograptus outcrop in and adjoining the valleys of the Thomson River near Mount Easton and Aberfeldy, and in the Big River near Enoch's Point.

Near Mount Easton they directly underlie the basal grit of the Walhalla beds and rest on the highly-cleaved fossiliferous black slates of Upper Ordovician age. The same sequence occurs near Enoch's Point (*vide* sections, fig. 2).

Lithologically, these beds are in the main black and greyish-green shales and mudstones, with some soft yellow and white and hard black micaceous sandstone.



1 Ordovician

2 Monograptus Beds
3 Basal Grit
4 Sandstones & Shales } Silurian
5 Holy Terror Grit
6 Upper Shales

O Basalt

Fig. 2.

Sections along lines A B and C D on geological locality map.

(The Upper Ordovician and Monograptus beds in and adjoining the valley of the Big River near Enoch's Point were discovered by Mr. O. A. L. Whitelaw in his survey of this area).

Horizontal Scale—1 in. = 2 miles.

Monograptus cf. dubius is abundant in certain bands of black shale, but other fossils are rare. Occasional worm tracks and remains of crinoids occur in places in these beds.

(*d.*) *Store Point–Mount Useful Beds.*—Below the eastern basal conglomerate of the Walhalla beds near Store Point and Mount Useful are certain beds which, in the absence of fossils, are included provisionally with the Lower Silurian. Lithologically, they differ essentially from the other sediments of this belt. The uppermost beds consist chiefly of thin-bedded highly-cleaved black slates. Underlying these beds, east of Store Point and near Mount Useful, are bands of purple shales and mudstones associated with green and white sandstones and quartzites, which are possibly of terrestrial origin.

According to Mr. O. A. L. Whitelaw (No. 57, p. 8), these beds overlie the fossiliferous strata of Upper Ordovician age, and, as indicated above, they underlie the basal grit of the Walhalla beds. Patient search by members of the Geological Survey for fossils in these beds has yielded negative results, with the exception of some fucoids (?).

Locally, these beds are highly crumpled and contorted, and crush conglomerates have been developed in places.

B.—DYKES OF DEVONIAN AGE.

(1) *General Remarks.*—Dyke rocks of Devonian age are very abundant throughout this region. They reach their maximum development in the central geosynclinal area between the western basal grit of the Walhalla beds and a line passing approximately through Jamieson, Ten-Mile, Johnson's Hill (near Wood's Point), Toombon, and the Eureka mine (near Walhalla). East of this line no dykes of this age are known. Between the Baw Baw, Mount Arnold, and Mount Torbrech granodiorite massifs and the western basal grit above mentioned, similar dykes are common in certain places, but with few exceptions they have yielded little gold. Furthermore, the dykes are not uniformly developed throughout the central belt, whose limits have been outlined above. They are most prevalent in the troughs of the geosyncline where the intensity of folding and fracturing has been greatest, as at Walhalla, near Toombon, Wood's Point, Gaffney's Creek, and Mount Terrible, between Enoch's Point and Ten-Mile. The geological and locality sketch map illustrates these relations very clearly.

In general, the dykes conform closely in strike and dip to the sedimentary rocks, and without doubt their intrusion was a concomitant of the folding of these sediments.

Normally, the dykes are narrow, averaging about 6 ft. in width, but occasionally they expand into lenticular bulges or expansions. The following figures are the approximate maximum dimensions of some of these expansions :—

Morning Star	1700 ft. x 280 ft.
Bald Hills dyke, near Matlock ..	950 ft. x 300 ft.
Toombon	900 ft. x 300 ft.
New Loch Fyne	700 ft. x 280 ft.
Luck's All	800 ft. x 200 ft.
Eldorado	640 ft. x 300 ft.

On the other hand, the Tubal Cain intrusion, as pointed out by W. Baragwanath (No. 2, p. 269), appears to be a volcanic neck or plug. It is roughly circular in plan—850 ft. x 750 ft.—has approximately vertical sides, and is composed largely of a rock of basaltic composition. It is quite distinct, however, from the basaltic necks of Tertiary age which are described below.

Considerable variation is evident in the texture and composition of the dyke expansions. Normally their borders are finer-grained and more basic than their interiors.

This is particularly well exemplified in the Morning Star dyke, where augite, ilmenite, and apatite are more concentrated in the finer-grained marginal *facies*; and in a lesser degree in the New Loch Fyne, Eldorado, and Luck's All dykes. The central portion of the Tubal Cain intrusion consists of a medium to coarse-grained gabbro-porphyrite which grades into a marginal fine-grained black basalt. Many of the narrow dykes exhibit chilled margins.

All these intrusions are truly hypabyssal, and their present exposed portions appear to have consolidated under no great thickness of overburden.

The rocks of the dyke bulges, although frequently resembling plutonic types in hand specimens, under the microscope invariably show a ground-mass of some sort. In the narrow dykes a porphyritic structure is the rule, and vesicles and a devitrified glassy base are present in some cases.

Thermal metamorphism of the surrounding strata is usually slight. Induration of the sediments in close vicinity to the larger dykes is common—*e.g.*, A 1, Morning Star, New Loch Fyne, &c.—but this alteration appears to be confined to a hydrothermal alteration—carbonation, sericitization, silicification, and pyritization—by solutions and vapours connected with the intrusion of the dykes and quartz-veins. Such alteration rarely extends for greater distances than 30 ft. from the dykes. Horses of sedimentary rocks included in the dykes show no signs of assimilation.

Coarsely-crystallized pegmatite veins are uncommon, but aplite veins and streaks of quartz and felspar not infrequently intersect the rocks of the dyke bulges.

(2) *Age of the Dykes.*—Concisely, the evidence for the Devonian age of these dykes is as follows:—

1. They are intrusive into the highest beds of the Upper Silurian.
2. They are overlain by the basal conglomerates of the Lower Carboniferous beds near Mansfield. These conglomerates in places carry a little alluvial gold which, presumably, has been derived from the dykes and reefs in the underlying Silurian rocks.
3. The writer knows of no cases of these dykes being intrusive into the Baw-Baw, Mount Arnold, and Mount Torbrech granodiorite massifs, although they occur in the contact rocks on their northern, eastern and western flanks. The granodiorite in turn is overlain, near Buxton, by the Cathedral sandstones which lithologically resemble closely the Mansfield beds of Lower Carboniferous age.

Hence it is seen that the age of these dykes is post-Upper Silurian and pre-Lower Carboniferous, and therefore Devonian.

(3) *Magmatic Differentiation.*—It is believed that these dyke rocks are all genetically related. The following evidence is advanced in support of this contention:—

Occurrence.—There exists a remarkable uniformity in the structural features of these intrusions. Narrow dykes, with elliptical expansions conforming closely to the strike of the sediments, sometimes for considerable distances, are the rule. As mentioned previously, the majority of the dykes occur within the geosynclinal area, and they are more abundant in the trough of the geosyncline than elsewhere.

Petrological Similarities.—(*a*) Brown hornblende was an original constituent of almost all these rocks. It is absent in the acid dykes (quartz porphyries) from Brohan's Reef, Thomson River and St. Lawrence dykes, and apparently in the Tubal Cain dyke.

(*b*) Ilmenite is another characteristic mineral of these rocks. Its relative abundance in some of them is reflected in their high percentages of TiO_2.

(*c*) Interstitial micrographic and cryptographic intergrowths of quartz and felspar are the rule in the coarser-grained rocks of the dyke expansions. The Aberfeldy peridotite and the acid dykes above mentioned do not show this structure.

Metasomatic Alteration.—Almost without exception these rocks have been metasomatically altered in a greater or lesser degree. Three main types of alteration are recognizable—

(*a*) Late magmatic alteration.
(*b*) Propylitization.
(*c*) Hydrothermal alteration by the vein-waters.

The chemical and mineralogical changes brought about by these alterations are remarkably uniform in character throughout the belt, suggesting strongly a common origin for the waters or gases responsible for the alteration. Furthermore, evidence will be adduced in the sequel to show that these waters and the dykes are of congeneric origin.

The widespread intimate association of auriferous quartz-veins with these intrusions further supports the idea of consanguinity.

The available evidence is insufficient, however, to discuss with any degree of positiveness the nature of the original magma and the *modus operandi* of its differentiation. It is probable that these dykes are related to the granodiorite massifs of Baw-Baw, &c., but in what way is not clear.

The constant appearance on Victorian goldfields of rocks of dioritic composition and of quartz porphyries, not far removed geographically or in age from granodioritic intrusions, is suggestive, in the writer's opinion, of some genetic relationship between them.

The general order of intrusion of these dykes is fairly clear. Broadly, the order appears to be one of increasing acidity. We find acid dykes, aplites, granophyres, and quartz-feldspar veins cutting many of the basic and ultra-basic rocks. The ultra-basic copper-bearing New Loch Fyne dyke has been altered along its contact by the normal diorite-porphyrite dyke. Furthermore, the residual magmatic extracts which have been squeezed through these rocks, causing the alterations mentioned above, appear to become progressively more acid. On the other hand, no case is known of a basic dyke of Devonian age cutting a more acid one.

C.—TERTIARY BASALTS.

Several small pipes of older basalt have been located by Mr. Baragwanath and Mr. Whitelaw in their surveys of this belt. Basalt-flows of the same age occur at Mount Lookout, at Moondarra, near Walhalla, and at numerous places on the Thomson–Aberfeldy divide between Aberfeldy and Beardmore's. As previously suggested, these last-named flows were probably once continuous, and came from Mount Lookout, Aberfeldy.

Petrologically, these rocks are normal olivine basalt, and call for no comment.* The pipe on the Reefton track, about 2 miles west of the junction of the two branches of the Thomson River, is interesting, inasmuch as it contains numerous inclusions of ultrabasic rocks—peridotites and pyroxenites—which are moderately rich in the spinels, pleonaste and picotite and chromite (?).

D.—STRUCTURAL FEATURES.

(1) *Folding.*—The structure of this belt is that of a corrugated geosyncline—the Walhalla geosyncline—between two geanticlines, the Matlock anticline on the west and the Black River–Mt. Selma anticline on the eastern flank. In general the beds are closely folded, and dips rarely become less than 50°. In the northern portion of this belt, between Jamieson and Gaffney's Creek, rapid alternation occurs in the direction of dip in places. In Hickey's

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* Petrological descriptions of some of these rocks are embodied in the papers by Dr. A. W. Howitt (No 25), Professor J. W. Gregory (No 17) and Professor E. W. Skeats (No. 43).

road cutting, on the coach road between Kevington and Ten-Mile, ten anticlines and ten synclines are exposed in a width of section of about 150 yd.

The average strike of the sediments is N.N.W. As will be seen from the geological sketch map (Plate I.), the Silurian strata bend round the Baw-Baw granodiorite massif, the intrusion of which appears to have caused this variation in the direction of the strike. It might be suggested that this curvature is due to the pitch of the beds, but this is not likely, as beds of the same horizon—*e.g.*, Monograptus slates and the western fossiliferous grit—can be traced on the surface for considerable distances, and there is no field evidence of any regional pitch.

(2) *Faulting.*—The faults in this belt may be subdivided broadly into the following types, viz. :—

- (A) Strike-faults.
  - (a) Dip slip faults.
  - (b) Strike slip faults.
- (B) Oblique faults.
- (C) Horizontal faults.

Faults of class (A) greatly outnumber those of the other classes. The bulk of the strike-faults appear to be connected with the folding of the strata, and they are frequently occupied by auriferous quartz-veins, and are therefore of considerable importance. Their recognition is often difficult, unless, as is often the case, they intersect and displace dykes.

Faulting of this nature appears to have taken place on an extensive scale before and immediately after the intrusion of the dykes. Strike-faults of later date than the formation of the auriferous quartz-veins are not common.

In dip slip faults the component of the movement in the direction of the dip of the fault has been greater than the component in the direction of the strike. Numerous examples of such faults have been seen in the mines near Enoch's Point, Kevington, Ten-Mile, and Gaffney's Creek. In nearly all cases they intersect and displace dykes. The displacement caused by these faults is rarely greater than 20 ft., but in one or two cases displacements of 40 or 50 ft. have been noted.

In strike slip faults the component of the slip along the fault-plane in the direction of the strike is greater than in the direction of the dip. Faults of this nature are fairly numerous, but, as in the former case, their recognition is difficult apart from some indicator such as a dyke or quartz reef. In many cases, as at the Blue Ribbon mine near Ten-Mile, Victor's Quartz, and at Claxton's Reef, near Toombon, these faults displace dykes, and quartz reefs have formed along them. The horizontal displacement at the Blue Ribbon mine, according to Whitelaw (No. 57, p. 13), is 158 ft.

Oblique faults or cross-courses are far less numerous than strike faults, and, unlike the latter, they do not appear to be connected with the folding of the strata, and are mostly of later age than the quartz reefs.

Many, if not most, of the reefs within the dyke expansions occur in faults which often displace the dykes for considerable distances. For instance, the famous Age of Progress reef in the Morning Star dyke appears to be filling a reversed strike-fault which displaces the dyke about 40 ft. Again, the large reef seen in the 600-ft. level in the same mine occurs in a similar fault which has displaced the dyke about 50 ft., and many other reefs in this dyke occupy faults. In the A1 and New Loch Fyne mines many of the reefs occur in faults which have displaced the dykes for varying distances, and, according to Mr. Baragwanath (No. 3, p. 42), the quartz reefs in the Eureka dyke, near Walhalla, occupy fault-planes. Faults later than the main reefs are rare in these dyke expansions.

E.—TYPES OF QUARTZ REEFS.

The reefs of this belt may be classified as follows :—

(1) Reefs occurring in or along walls of dykes.
(2) Reefs occupying fault-planes, intersecting or in close association with dykes.
(3) Bedded reefs.
(4) Fault-reefs apparently not associated with dykes.
(5) Gash veins and stockworks in sedimentary rocks.

From an economic standpoint the first two classes have proved to be most important.

(1) *Reefs Occurring in or along Walls of Dykes.*—The dyke reefs have more extensive development, and have been worked to a much greater degree than any of the other types. They occur in various ways—

(*a*) As relatively flat veins or "floors," dipping at small angles from wall to wall of the dyke, and sometimes continuing out into the surrounding strata. Particularly fine examples of this type can be seen in many of the narrow dykes—*e.g.*, Waverly, May Moon, Georgia, Dempsey's, Excelsior, Hunt's, &c. In the majority of cases the reefs stop short at the dyke walls. More commonly the reefs dip at angles between 30° and 50° from wall to wall, as in the A 1, Morning Star, New Loch Fyne, Eldorado, Luck's All, and Eureka dykes. In the A 1 and Morning Star mines, and less commonly in the New Loch Fyne, the reefs dip alternately in opposite directions, as is seen in figs. 3 and 4.

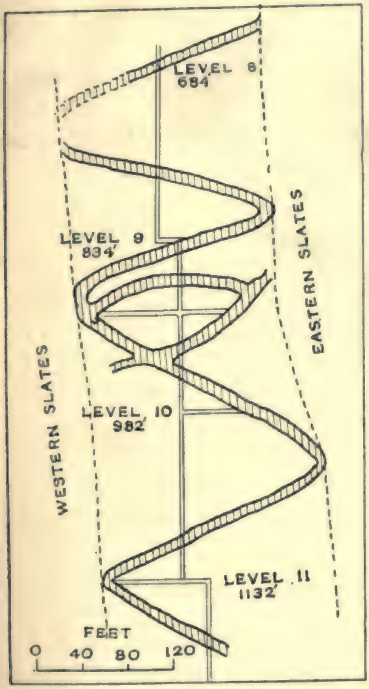

FIG. 3.

TRANSVERSE SECTION THROUGH THE A 1 GOLD MINE SHOWING ARRANGEMENT OF QUARTZ REEFS.

Reduced from section by Mr. P. D. M'Kenzie, Surveyor to the A 1 mine.

(*b*) Transversely from wall to wall, and dipping at angles approaching the vertical. Reefs of this type are occasionally met with in some mines—*e.g.*, Working Miners', Kevington.

(*c*) Steeply-dipping longitudinal reefs.—These are not uncommon, but are rarely payably auriferous, except occasionally at or in close vicinity to their junctions with flat veins, as at the Little Comet mine. At the A 1 mine reefs of this sort sometimes fill fault-fissures which intersect and displace the main floors for a few inches.

At the New Loch Fyne mine, narrow, steeply-dipping, poorly-auriferous veins, which strike approximately north and south, and apparently occupy fault-planes, intersect the main floors of quartz. They appear in some cases to be the feeders for the main reefs.

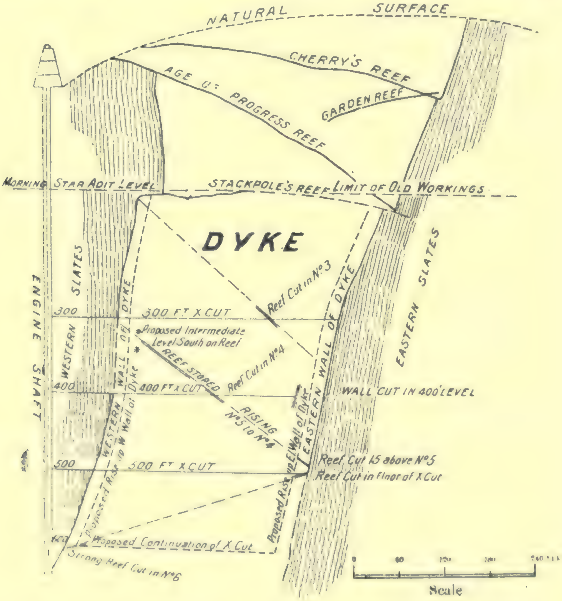

FIG. 4.

TRANSVERSE SECTION THROUGH THE NEW ENGINE SHAFT, MORNING STAR DYKE, WOOD'S POINT.

Showing arrangement of quartz reefs within the dyke. Reproduced from Mr. O. A. L. Whitelaw's section in the prospectus of the Morning Star G.M. Co.

(*d*) Reefs along dyke walls.—Reefs of this type have been worked at the Domino mine, near Jamieson, Brohan's reef, and the Bristol reef, near Gaffney's Creek. They have yielded little gold.

(*e*) Stockworks.—In many of the narrow dykes—*e.g.*, Rose of Denmark and Working Miners'—and in some of the larger ones the quartz veins ramify through the rocks in all directions, forming typical stockworks. In such cases the whole of the dyke is crushed if within the shoot of gold.

(2) *Reefs Occupying Fault-Planes, &c.*—Fault reefs which intersect and displace dykes occur in numerous places between Kevington, Enoch's Point, and Gaffney's Creek, and near Aberfeldy. They have been worked with some success at the Alabama, Home Rule, Victor's Quartz, and Toombon mines, and also at Alexandra, which is outside this belt. Almost without exception they are richest at the intersections with the dykes, and are usually enlarged in this vicinity.

Cohen's, Lily, Harbinger, and All Nations are examples of reefs within fault-fissures in close association with dykes.

(3) *Bedded Reefs.*—Mr. Whitelaw (No. 57, p. 20) has shown that the reef worked at the Royal Standard mine was an inverted saddle reef, and, according to Mr. Dunn (No. 13, p. 42), some of the reefs worked at the United Gleeson's, Star of the West, and Blue Ribbon mines, near Ten-Mile, were of a similar type. Mr. W. Baragwanath informs me that a saddle reef was worked at the White Star mine near Mount Useful.

Diagrammatic illustrations of bedded saddle and inverted saddle reefs on a small scale can be seen in Hickey's road cutting, near Ten-Mile, and at Walhalla. In each case they are closely associated with faults.

(4) *Fault Reefs Apparently not Associated with Dykes.*—A narrow belt lacking in dykes and containing some important auriferous reefs extends from near Knockwood on the north to Store Point and Fulton's Creek at the south end. The reefs in this zone mostly occupy faults which conform closely with the adjoining strata. Bedded reefs have been worked at the Royal Standard and White Star mines, and also at Store Point.

These reefs are generally well laminated and highly mineralized, particularly so at Store Point, where considerable amounts of chalcopyrite, galena, arsenopyrite, and pyrite are present in the veins. Stibnite also occurs in these reefs at the Leviathan, Leichhardt, and Royal Standard mines.

The most productive mines in this belt have been the Leviathan, Royal Standard, Crinoline, Bismarck, and Gippsland Consols.

(5) *Gash-Veins and Stockworks in Sedimentary Rocks.*—Reefs of this type are relatively common in the central dyke belt. They are best developed in thick bands of sandstone, in which they occur either as more or less flat floors which normally end abruptly at the walls of the sandstone bed, or as stockwork formations. Frequently they are seen to be fed by small bedded fault-veins. Reefs of this kind were often very rich near the surface—*e.g.*, Never Mind, near Wood's Point, which is reported to have yielded about 7000 ozs. of gold from surface to a depth of 100 ft.—but in no case have they proved payable below water-level.

3.—PETROLOGY.

A.—PREVIOUS LITERATURE.

Professor E. W. Skeats (No. 43), in an appendix to Mr. O. A. L. Whitelaw's report on the Wood's Point district, has summarized the results of previous workers on the petrology of the auriferous dyke rocks of this area. He also examined thin sections of many of the dykes and described in detail the microscopical characters of the New Loch Fyne dyke. He speaks of these rocks as propylitized diorites and hornblende porphyrites, and suggests that they are probably apophyses of buried granodiorite masses, probably of Lower Devonian age. Professor Skeats agrees in the main with the present writer's conclusion (No. 28, p. 128) that the regional propylitization of the rocks is independent and earlier than the introduction of the gold-bearing vein solutions. He furthermore shows that Professor Gregory's use of the term "propylitization" was a somewhat loose one, and states that all the dyke rocks described by Professor Gregory should be regarded as propylitized, and not simply the more-altered rocks to which he restricted the term, and, further, that some of the rocks regarded by the latter as propylitized diorites had suffered not only propylitization but also hydrothermal alteration by the vein-solutions.

Professor Skeats described the New Loch Fyne dyke as a propylitized quartz hornblende diorite consisting chiefly of chloritized brown hornblende crystals, porphyritic zoned plagioclase—oligoclase to labradorite—ilmenite, and a little (probably secondary) interstitial quartz and orthoclase. The micrographic intergrowth of quartz and feldspar he regards as probably one of the effects of propylitization on the ground-mass of the rock.

Professor Skeats also draws attention to the remarkable resemblance between the field occurrence and petrological characters of the dyke rocks from the New Loch Fyne mine and those from Wood's Point and Gaffney's Creek.

Apart from the above-mentioned petrological examinations of certain of the dykes from the Wood's Point district by Mr. Mennell and Professors Gregory and Skeats, the only other rocks whose microscopical characters have been studied are certain ones from the Walhalla district.

The late Dr. A. W. Howitt (No. 25) described samples of the dykes from the Long Tunnel, Long Tunnel Extended, Great South Long Tunnel, Longfellow's, and the Walhalla Proprietary mines, as quartz mica diorites which sometimes contain hornblende. The Thomson River copper mine dyke he determined to be a hornblende diorite with a little quartz, and the Tubal Cain rock an augite bearing mica and hornblende diorite. A dyke from the locality marked Note 24 near the Eureka mine on the geological plan of Walhalla he described as a normal olivine basalt.

B.—DETAILED DESCRIPTION.

The Devonian dyke rocks of this belt may be classified as follows :—

(*a*) Quartz-feldspar porphyries, granophyres, and aplites.
(*b*) Diorite porphyrites.
(*c*) Lamprophyres.
(*d*) Gabbro porphyrites and basalts.
(*e*) Ultra-basic rocks—peridotite and perknites.

Auriferous quartz-veins are associated with all these rocks, with the exception of class (*e*), but by far the most economically important reefs occur in or in close relation to rocks of classes (*b*) and (*c*).

(*a*) *Quartz-Feldspar Porphyries, &c.*—Rocks of quartz-feldspar porphyry type occur in a few places in the southern portion of the belt. For the exact location of some of these rocks and for specimens of same the writer is indebted to Mr. W. Baragwanath.

Quartz-feldspar porphyry, 50 ft. wide, junction of Jordan and Thomson Rivers.—In hand specimens it is a yellowish-green aphanitic rock, with minute crystals of pyrite and arsenopyrite disseminated through it.

Examined microscopically, it is seen to have consisted originally of porphyritic phenocrysts of feldspar, now almost entirely replaced by sericite and a little pyrite, and smaller ones of biotite and quartz in a microcrystalline ground-mass consisting chiefly of quartz grains and wisps of sericitic mica. Ilmenite and apatite are accessories. The biotite has been bleached, and rutile needles have separated out. Pyrite crystals having the form of the pyritohedron replace the biotite in places. The rock has been extensively sericitized, and a little secondary quartz and pyrite have been developed. Carbonates are absent.

No. J3, Sericitized quartz-feldspar porphyry, Brohan's Reef, near Aberfeldy.—This rock consists of idiomorphic phenocrysts of feldspar now entirely sericitized, and occasional corroded phenocrysts of quartz in a crypto-crystalline ground-mass made up chiefly of sericite and finely-divided quartz. A few small laths of bleached and pyritized titaniferous biotite are present. Numerous idiomorphic crystals of pyrite replace the ground-mass. The larger ones are surrounded by fringes of secondary quartz.

Quartz-feldspar porphyry dyke, Waterloo Gully, south-west of Aberfeldy.—This rock consists of greatly sericitized panidiomorphic phenocrysts of orthoclase and subordinate acid plagioclase (albite-oligoclase), prismatic laths of bleached biotite, including abundant rutile and a few corroded pellucid crystals of quartz in a microcrystalline ground-mass made up of quartz grains, microlites of feldspar, and sericite flakes. Zircon and apatite are accessories. One or two vesicles now filled with secondary quartz are present. Dusty sericite is the most abundant secondary mineral. Some pyrite and carbonates are also present.

No. 238, Dyke, Walhalla Proprietary Company. — A holocrystalline rock consisting of abundant phenocrysts of feldspar, panidiomorphic quartz, and bleached biotite, from which rutile, sphene and iron oxides have separated. A little interstitial micropegmatite is distributed through the section, and massive carbonate fills interstices between the quartz and feldspar crystals in places, and in part replaces the quartz. Orthoclase appears to be in excess of plagioclase, which is andesine, but both are much sericitized, and it is difficult to determine their relative proportions. A little pyrite replaces the biotite and feldspar. Nomenclature: Altered quartz-feldspar porphyry.

No. 872, Mines Department Collection, St. Lawrence dyke, Aberfeldy River.—This rock consists for the most part of long prisms of plagioclase (oligoclase) and orthoclase in approximately equal amounts. A little biotite, ilmenite, quartz, and accessory apatite are also present. A micrographic intergrowth of quartz and feldspar can be seen in parts of the section. Carbonates and sericite have been extensively formed, also a little chlorite, and grains of pyrite which replace ilmenite.

Granophyres.—These are acid rocks occurring as dykes and veins, and consisting largely of orthoclase, quartz, and hornblende in a ground-mass which is made up of abundant beautiful micrographic and pseudospherulitic intergrowths of quartz and feldspar. The best known examples from this belt are the Alabama dyke, near Matlock; Raymond's dyke, near Gaffney's Creek; dyke crossing the "r" in "Jericho" on geological and locality sketch map (Plate I.); and a vein in the Eldorado dyke (diorite-porphyrite), near Gaffney's Creek.

The Alabama granophyre is associated with a basic gabbro-diorite or porphyrite, but the field relation between the two types could not be determined.

Quartz-veins occur within all these granophyres, but they have yielded negligible quantities of gold.

Granophyre, Alabama dyke, Matlock.—A thin section of this rock shows phenocrysts of orthoclase, plagioclase, quartz, and abundant pseudomorphs after hornblende with a little biotite, all embraced by beautiful interstitial micrographic and pseudo-spherulitic intergrowths of quartz and feldspar. Orthoclase is greatly in excess of plagioclase, which latter is referable to albite-oligoclase. The orthoclase contains occasional microperthitic inclusions of albite and idiomorphic crystals of hornblende. Epidote, sericite, and carbonates replace it in part. Generally the intergrowths of quartz and feldspar occur as fringes to the phenocrysts of orthoclase and plagioclase, but sometimes they merge into one another. Some splendid pseudomorphs of carbonates and microspherulitic chlorite after idiomorphic hornblende are seen in the section. Grains of leucoxene and sphene have separated out from the hornblende on its alteration, and these have been concentrated for the most part along the margins of the crystals. A little secondary quartz has been formed at the same time. Massive interstitial carbonate is distributed through the section. It is distinct from the carbonate replacing the hornblende, &c., and is essentially contemporaneous with the granophyric intergrowths of quartz and feldspar, and in one place in the section is apparently intergrown with quartz. Microspherulitic chlorite is common. It occurs in two ways—

1. Massive, marginal to carbonates, and in part replacing them.
2. In granular form, replacing hornblende.

A feature of interest in this rock is the relative abundance of a pleochroic—colourless to yellow—mineral, in radial and stellate aggregates, which often have a nucleus of chlorite or carbonate. Viewed under the high power, it appears as pointed prisms which have a higher refractive index than apatite and all sections of carbonate. Under crossed nicols it shows bright polarization colours of second or third order, and extinguishes parallel to the length of the prisms. To determine the precise optical characters of the mineral, some of the rock was crushed to pass a 1 mm. sieve, and the heavy and light portions were separated by bromoform, G. = 2.80. The heavy residue was dried and the abundant ilmenite and leucoxene were separated by an electromagnet. The remaining material was hand-picked under the microscope, and numerous grains of the doubtful mineral were collected. Determination of its refractive index showed that its R.I. in all cases was greater than R.I. monobromonapthalene = 1.658. Some of the grains were mounted on a glass slip and viewed under convergent polarized light. They showed a central straight bar, which curved very slightly on rotation of the stage, proving the mineral to have a large axial angle. Determination of its sign showed that it is —*ve*. The above-mentioned properties agree closely with those of epidote. Interlaminated with the epidote in places are prisms of a colourless mineral having a lower refractive index than the epidote, and exhibiting ultra blue polarization colours. It is therefore zoisite.

Granophyre, Raymond's Dyke, near Hunt's mine, Gaffney's Creek.—A thin section of this rock is composed chiefly of large relatively fresh phenocrysts of orthoclase feldspar with subordinate plagioclase (oligoclase), long laths of biotite, idiomorphic phenocrysts of hornblende, and irregular-shaped grains of quartz in a ground-mass made up chiefly of microspherulitic and micrographic intergrowths of quartz and feldspar, which generally have a nucleus of sericitized feldspar and quartz. Leucoxene, idiomorphic crystals of sphene, and apatite are accessories. Both the hornblende and the biotite have been entirely replaced. The hornblende exhibits its usual type of alteration to aggregates of pennine and carbonates, with the separation of sphene and rutile. Pennine is the most common alteration-product of the biotite, but white mica and carbonates are often developed; rutile has separated out. Abundant dusty carbonates, pennine, sericite, and a little pyrite are secondary minerals.

Granophyre, dyke bulge in Ordovician strata at the "r" in "Jericho" on geological and locality map (Plate I.).—This rock, in thin section, resembles closely the dyke from the Alabama mine, Matlock. It consists of panidiomorphic phenocrysts of hornblende which are bleached, are partially replaced by pennine and a little epidote and large phenocrysts of feldspar, in a ground-mass consisting chiefly of beautiful granophyric intergrowths of quartz and feldspar with a little hornblende and granular secondary quartz. Sphene and apatite are accessories. Orthoclase preponderates over plagioclase, which latter is referable to oligoclase-andesine. The usual alteration-product of the feldspar—namely, sericite—is very rare, but pennine, epidote, sphene, and fairly abundant zoisite replace it. No carbonates are present.

Granophyre vein in diorite porphyrite, lower adit level, Eldorado mine.—This rock consists for the most part of idiomorphic phenocrysts of hornblende and feldspar, which latter is mainly orthoclase, in a granophyric intergrowth of quartz and feldspar. Phenocrysts of quartz are lacking, and, apart from the intergrowth with feldspar, it is very rare in the ground-mass of the rock. One or two large phenocrysts of plagioclase are seen in the section. These give symmetrical extinction angles of 21° and 24° respectively, and have greater refractive index than orthoclase adjoining, and are therefore andesine. Sericite, carbonates, and a little epidote and chlorite replace some of the feldspar, but for the greater part it is remarkably fresh. The hornblende is much less altered than usual, and occurs in idiomorphic crystals which are often included in the feldspar. The granophyric intergrowth normally occurs marginal to feldspar phenocrysts, but in places penetrates and veins the feldspar. Sphene and ilmenite are accessories. Chlorite, sericite, leucoxene, and a little carbonate and pyrite are secondary.

Aplite.—Rocks of this type occur as veins or narrow dykes traversing the more basic rocks.

Section No. 460 of aplite vein traversing the Eureka dyke near Walhalla is characteristic of this type. It is a holocrystalline rock composed of laths of little-altered biotite, prisms of sericitized feldspar which is chiefly albite, and irregular grains of quartz and needles of ilmenite, all apparently intergrown with one another. Rutile needles have separated out from the biotite, and a little pyrrhotite is scattered through the section.

No. 294, aplite vein in basalt, Coronation mine, Tubal Cain dyke.—This is an even-textured medium to fine-grained rock, consisting chiefly of granular pink feldspar and green prisms of augite with some quartz. Microscopically, it consists of greatly chloritized phenocrysts of augite in a mosaic of granular quartz, sericitized and epidotized feldspar—orthoclase slightly exceeds the plagioclase (albite) in amount—ilmenite, white mica, and apatite. The quartz and feldspar exhibit a tendency to graphic intergrowth. The usual hornblende and carbonates are absent from this rock. In addition to chlorite, some serpentine and epidote have developed from the augite.

No. 252, acid vein (aplite) traversing hornblendite, Shamrock dyke, south of Wood's Point.—This rock consists of large panidiomorphic phenocrysts of hornblende and feldspar and occasional ones of quartz, in a ground-mass made up of mosaics of quartz, laths of feldspar, and idiomorphic crystals of hornblende. Ilmenite, sphene, and apatite are accessories, and chlorite, carbonates, sericite, leucoxene, and pyrite are secondary. Tremolitic and actinolitic outgrowths to the brown hornblende phenocrysts are common. They include crystals of ilmenite and pyrite. The feldspar is chiefly orthoclase. It occurs usually in relatively fresh large idiomorphic phenocrysts containing microperthitic inclusions of albite. Carlsbad twinning is usual, but one fine Manebach twin is also present. Minute prisms and grains of a highly refracting mineral, pleochroic—colourless to light pink—extinguishing parallel to the rectangular cleavage planes, and having polarization colours resembling those of calcite, and therefore sphene, are common. Microspherulitic pennine, sericite, and massive carbonates are abundant. The carbonates appear to be essentially contemporaneous with the quartz.

No. 21, aplite vein in Morning Star dyke, west edge, 400-ft. level.—This rock is very highly altered, and determination of its original characters is difficult. Apparently it originally consisted chiefly of granular quartz laths and prisms of sericitized and partly carbonated feldspar—orthoclase and acid plagioclase—and laths of biotite now replaced by pennine and fairly abundant prisms and hypidiomorphic grains of ilmenite and leucoxene. No hornblende is recognizable. Sericite, chlorite, and carbonates are secondary.

(*b*) *Diorite Porphyrites.*—The type rocks of this series are the Morning Star, New Loch Fyne, and Jericho dykes. They have many affinities with the "Markfield" type (diorite granophyre) of the English nomenclature. Economically, these rocks are of considerable importance, as many of the best mines in this belt occur within them. Their petrological features and the nature of the metasomatic alteration undergone by them are furthermore of considerable interest.

The Morning Star rock is the best known and perhaps the most interesting of the series. In hand specimen it is a black and white even-grained rock, consisting chiefly of black hornblende and white feldspar. A little quartz and biotite are also recognizable. Microscopically, the rock is composed of phenocrysts of brown hornblende—penetrated sub-ophitically in places by greatly sericitized laths of plagioclase—frequently having a core of augite and including abundant grains of ilmenite and apatite; panidiomorphic phenocrysts of andesine now extensively sericitized, long laths of biotite and panidiomorphic quartz in a ground-mass made up of hornblende, feldspar laths, granular augite, and a micrographic intergrowth of quartz and feldspar. The relationship between the hornblende and augite is interesting. In some cases the augite is fringed by brown hornblende, which includes much ilmenite, and in others it occurs as an irregular mosaic of grains surrounded by massive hornblende. Ilmenite rarely is included in augite. It seems to be practically all confined to areas of hornblende.

During the consolidation of the rock it was permeated by residual siliceous and alkaline carbonate extracts released by the magma, with the result that the interstices in the rock were filled with quartz, micrographic intergrowths of quartz and feldspar, albite, and carbonates. Actinolitic and tremolitic outgrowths to the hornblende were formed at the same time. Large quartz crystals, which include clear crystals of albite, occur in optical continuity with the quartz of the intergrowths. The massive carbonate appears to be contemporaneous with the quartz.

As a result of a slightly later phase of this alteration, chlorite, serpentine, epidote, and sphene were formed from the hornblende and biotite, leucoxene was developed from ilmenite, and the feldspars were chloritized and sericitized. These minerals are the ones characteristic of the type of alteration spoken of as propylitization.

At a still later period the rock was fractured and penetrated by veinlets of quartz and carbonates.

Specimen analyzed, 10 ft. from Cherry's reef, Hope adit level, Morning Star dyke.—Augite and biotite are less common than in the preceding rock. However, numerous kernels of augite occur surrounded by patches of serpentine and microspherulitic chlorite, which apparently represent replaced augite. The feldspars are partially sericitized, and a little pyrite replaces some of leucoxene. Interstitial micropegmatite is fairly abundant, and generally has a nucleus of highly altered plagioclase (? andesine). Apatite is common. An analysis of this rock is given on p. 188.

New Loch Fyne dyke, No. 5 adit level.—This rock consists in thin section of porphyritic phenocrysts of panidiomorphic hornblende and some cloudy plagioclase and secondary quartz in a ground-mass of feldspar laths and granules of quartz, hornblende, ilmenite, and apatite. A little interstitial micropegmatite occurs in places. Coarse carbonate, chlorite (pennine), muscovite, sericite, leucoxene, albite, quartz, and pyrite are secondary minerals. The hornblende is the usual brown variety, with tremolitic and actinolitic outgrowths, and includes plagioclase laths and ilmenite, and often is sub-ophitically penetrated by the feldspar. It appears to have separated from the magma after the ilmenite and andesine. Augite is rare or absent. Two generations of feldspar are present. The first type is highly sericitized and zoned plagioclase (? andesine). The second type is in the form of relatively fresh laths of plagioclase having a refractive index less than quartz and showing symmetrical extinction angles of 16° from the twin lamellæ, proving it to be albite. It appears to be secondary and to be formed at the same time as the micropegmatite. Orthoclase is uncommon. It occasionally includes microperthitic albite. Many of the quartz-phenocrysts are in optical continuity with the micropegmatite, and both are of later origin than the main consolidation of the rock. Ilmenite is largely altered to leucoxene.

No. 100, Jericho dyke, near Jordan River, Jericho.—It is an even-textured melanocratic rock composed for the most part of black plates and prisms of hornblende and occasional feldspar phenocrysts. A little pyrite occurs disseminated through the rock.

Under the microscope it consists of abundant panidiomorphic phenocrysts of hornblende—partially bleached and converted into actinolite—including micropœcilitically granules of augite, feldspar, and apatite—and a few phenocrysts of clear albite and quartz in a ground-mass consisting of granular augite, euhedral hornblende and a little ilmenite, interstitial quartz, and feldspar. The two latter minerals are occasionally intergrown with one another. A little pennine and massive carbonate and a few euhedral pyrite crystals have been formed, but on the whole the rock is very free from alteration. The original rock consisted entirely of hornblende and augite, with a little plagioclase feldspar. A more acid residuum from the magma attacked the rock during cooling, with the development of quartz and albite and a little carbonate.

No. 65, diorite porphyrite dyke, near Franklin mine, south of Wood's Point.—This rock is composed of large hypidiomorphic phenocrysts of brown-green hornblende in which x and y = light brown and z = deep greenish-brown, prisms of clear feldspar, predominantly albite, which surrounds and includes some of the hornblende, and pseudomorphs of sericitic mica after phenocrysts of feldspar of doubtful nature, in a ground-mass made up of idiomorphic hornblende, clear feldspar laths, and a little quartz —the bulk of the latter being in the form of a granophyric intergrowth with the feldspar. A little leucoxene and idiomorphic sphene replace the ilmenite. A moderate amount of a colourless or slightly yellow mineral in stellate and radial aggregates is distributed through the section. It is apparently non-pleochroic; its polarization colours are less than those of hornblende, and it shows straight extinction. It is probably anthophyllite.

Wallaby dyke, Gaffney's Creek.—This is a rock of the normal Morning Star type. The hornblende is the usual brown variety, highly chloritized in places, and including much skeletal ilmenite and leucoxene. Pyrites replaces some of the ilmenite. The bulk of the feldspar is highly sericitized. Some of it has a refractive index less than quartz, and gives symmetrical extinction angles of 17°, and is therefore albite, but some orthoclase is also present. Pellucid quartz and micropegmatite are fairly common.

Quartz diorite porphyrite, Eureka dyke, Walhalla.—This rock is composed of idiomorphic phenocrysts of chloritized brown hornblende, prisms of greatly altered feldspar, and some clear quartz in a ground-mass of feldspar laths, granular quartz, and hornblende. Ilmenite and apatite are accessories. Secondary minerals are chlorite, sericite, kaolin, and a little carbonate and pyrite, which latter mineral replaces ilmenite for the most part.

No. 241, Walhalla Proprietary Company dyke, lower adit level. —This is a rock of the Morning Star type, consisting of panidiomorphic phenocrysts of brown hornblende greatly altered to chlorite and epidote with separation of rutile or sphene, columnar crystals of greatly sericitized, kaolinized, and chloritized plagioclase, referable to albite where its characters are determinate, and clear grains of quartz in a ground-mass made up of augite grains, hornblende, plagioclase laths, and a micropegmatitic intergrowth of quartz and feldspar. Ilmenite and a few large crystals of apatite are accessories. The former, for the most part, occurs included in hornblende, and is usually altered to leucoxene. Nomenclature: Quartz diorite porphyrite.

Diorite porphyrite, Thomson River copper mine, near Walhalla. —Variation occurs in this intrusion from the normal diorite porphyrite to a melanocratic rock composed almost entirely of hornblende and a little augite. The normal rock, examined microscopically, consists of abundant panidiomorphic phenocrysts of brown hornblende, a small amount of colourless augite, and isolated phenocrysts of clear orthoclase and albite in a matrix of hornblende, augite, feldspar, and interstitial quartz and micropegmatite. Much of the hornblende is converted marginally into actinolite, and the usual tremolitic outgrowths are common.

Certain basal sections of the hornblende exhibit the form (100 and are therefore anomalous. Inclusions of augite, ilmenit leucoxene, apatite and feldspar are present in the hornblend The augite occurs in granular form, and rarely as phenocryst Plagioclase, which is albite or oligoclase, occurs as hypidiomorphi phenocrysts which sometimes exhibit both pericline and albit twinning. They include both hornblende and augite, and ofte appear to be interstitial. A little sericite has developed in place from the feldspar, but on the whole it is remarkably fresh. Thi rock has suffered very little alteration. Some carbonate and little chlorite, sericite, pyrrhotite, and pyrite are present in th section.

Specimen No. 220 of the same dyke has suffered greater metasomatic alteration. The breaking down of the hornblende is wel seen. Microscopic veinlets of carbonates traverse it, and patche of chlorite have developed in association with them. In th augite the carbonate veinlets are arranged chiefly along th cleavage planes, giving an effect similar to the mesh structure i serpentine after olivine. Sericite and carbonates replace som of the feldspar. Granular and massive copper and iron pyrites associated intimately with carbonates and secondary quartz, ar not uncommon. Some of the quartz and feldspar crystals in thi section are in optical continuity with the micropegmatite. It i probable they were all formed at the same time by the squeezin of the residual salic magmatic extracts through the cooling rock

(*c*) *Lamprophyres*.—Dykes of this type are of widesprea occurrence. Locally—as near Gaffney's Creek, Wood's Point Matlock, and Jericho—they reach great development. From th surface to a depth of about 100 ft., on an average, and in place to 300 ft., they are so badly weathered that thin sections canno be cut to determine their petrological characters; consequently it is generally only when auriferous veins have been worked in them or when they have been intersected in mining operation that unweathered specimens for sectioning can be obtained. In hand specimens they are normally green or grey fine-grained or aphanitic rocks. Petrologically they appear to be mica and hornblende lamprophyres for the most part. When they expand into the so-called dyke-bulges they grade into diorite porphyrites of the Morning Star type. Their ground-mass is usually pilotaxitic or trachytic, and sometimes microcrystalline. In certain cases it is clearly devitrified glass. Vesicles are common in some specimens. Micrographic intergrowths of quartz and feldspar are very rare in these rocks. They are, without exception, more or less altered, and occasionally the alteration has been so severe that their original characters are indeterminate. They generally contain or are associated with quartz-veins which frequently occur in the form of floors or ladder veins.

Hornblende mica lamprophyre (minette), Morning Star dyke, width 6 ft., from immediately south of the dyke expansion.—A thin section of the rock shows that it consisted originally of phenocrysts of brown hornblende, feldspar—predominantly orthoclase—biotite, and a little quartz in a ground-mass made up of prisms of orthoclase, flakes of biotite, and grains of quartz and ilmenite. No hornblende remains, although its characteristic outlines are preserved in pseudomorphs of granular carbonates and chlorite with a little quartz. Carbonates and a little chlorite and quartz replace most of the biotite. A small quantity of euhedral magnetite has separated from the biotite as a result of the alteration. The plagioclase appears to be chiefly albite–oligoclase. Aggregates of sericite, carbonates, and quartz replace it and the orthoclase. Microscopical grains and crystals of pyrite have been freely developed. They display a preference for chlorite areas, and in such cases are euhedral. When replacing leucoxene or ilmenite they are usually in anhedral grains.

No. J40, hornblende lamprophyre (spessartite), Luck's All dyke, Warner's Creek, near Enoch's Point.—An even, medium-grained rock, dark in colour, made up almost entirely of chloritized laths and prisms of feldspar which is chiefly plagioclase–andesine type. Quartz is very rare. Micropegmatite is absent. Skeletal crystals of ilmenite partially changed to leucoxene and partially replaced by pyrite are common. Pennine, with a little carbonate, is the usual alteration-product of the hornblende and sericite with occasional crystals of zoisite of the feldspars. The feldspar laths penetrate the hornblende crystals ophitically in parts of the section.

Hornblende lamprophyre, No. 6, 600-ft. level below main adit, Rose of Denmark mine, Gaffney's Creek.—This is a holocrystalline leucocratic rock, consisting of phenocrysts of feldspar, pseudomorphs of chlorite and carbonate after hornblende, and quartz in a greatly altered ground-mass, part of which is in the form of micropegmatite. Plagioclase (albite) predominates over orthoclase. The latter mineral is partially replaced by rhombs of carbonate and flakes of sericite. Abundant leucoxene and a little pyrite replace the ilmenite. Needles of apatite are plentiful.

Specimen No. 5, micaceous dyke (? mica lamprophyre), No. 5 level, Rose of Denmark mine.—No femic minerals remain, and the feldspar is indeterminable owing to extreme sericitization. Numerous long curved flakes of white mica, which include rutile and are greatly replaced by carbonate and elliptical grains of quartz along the cleavage planes, are secondary after original biotite. A moderate amount of granular quartz, partially sericitized and carbonated, occurs in the section.

No. J2, hornblende mica lamprophyre (camptonite), 850-ft. level, A1 mine ; analysed specimen.—This rock shows considerable similarity in texture and mineral composition to the Morning Star and New Loch Fyne dykes, but is finer-grained and more altered than the average specimens of these rocks. The hornblende is generally bleached and greatly replaced by pennine and carbonates. Laths of plagioclase are included in the hornblende. Hypidiomorphic prisms and laths of much sericitized feldspar are common. Determination of its specific characters is difficult. It appears to be chiefly acid plagioclase with some orthoclase. An interesting feature of the rock is the presence of abundant hexagonal sections of greyish-black, semi-translucent leucoxene, which replace ilmenite. They are often in skeletal growths showing the characteristic triangular parting. Granular pyrite replaces much of the leucoxene. In only one place in the section is pyrite separated from leucoxene. Some micropegmatite and quartz are also present. Abundant pennine and carbonates and some sericite have been developed at the expense of the original minerals.

Some of the ilmenite and leucoxene were separated from portion of the crushed rock after passing through the 1 mm. sieve by means of bromoform and an electro-magnet, and examined chemically. In addition to FeO and TiO_2 in the ilmenite, a small quantity of MnO was also detected.

A little of the leucoxene was dissolved on a lid of a platinum crucible in 2 or 3 drops of HF, and dilute H_2SO_4 was added in excess. Some of the solution was transferred to a glass slip and evaporated to dryness. Abundant prisms and needles of gypsum were formed, proving the presence of CaO. Reactions were also obtained for FeO, TiO_2, and SiO_2.

No. J17, coarse micaceous dyke, mica hornblende lamprophyre (camptonite), 700-ft. level, A 1 mine.—Hornblende has vanished from this rock. Its place is taken by chlorite, carbonates, and leucoxene. Traces of biotite remain, but the bulk of it has been replaced by carbonates, chlorite, and lenticles of quartz. Sagenitic webs of rutile occur in the altered biotite. The feldspars are replaced in part by chlorite and carbonates, but sericite is uncommon. The usual pennine and carbonates permeate the rock, and occasional grains of pyrite are disseminated through it.

No. J23, aphanitic dyke, stopes below 850-ft. level, in vicinity of rich ore, A 1 mine.—In hand specimen this is a very dense rock, containing numerous patches of a green mineral. Extreme alteration (carbonation and sericitization) mask the characters of the rock. None of the original minerals, with the single exception of ilmenite, remain. Dense aggregates of dusty carbonates, laths of sericite, and a little quartz, pyrite, and chlorite, replace the rock. Veinlets of quartz with some carbonates traverse it.

Mica lamprophyre (? camptonite), Alabama mine, Ten-Mile.—This is a grey-coloured, vesicular, fine-grained rock. Grains of pyrite are disseminated through it. Microscopically it is a fine and even-textured greatly-altered rock, consisting mainly of laths of albite, flakes of white mica secondary after biotite, grains of clear quartz, and abundant disseminated carbonates and sericite. Small patches of chlorite are present, and grains of ilmenite, leucoxene, and pyrite are not uncommon. The vesicles are filled with bladed radiating magnesite and lined with grains of quartz.

Mica lamprophyre, Hunt's dyke, Gaffney's Creek.—As usual, the original characters of the rock are greatly masked by the ubiquitous development of carbonates, sericite, chlorite, and serpentine. Phenocrysts of biotite, apparently, were common in the original rock. They are now almost entirely replaced by chlorite, serpentine, white mica, and "sagenite webs" of rutile. Traces of feldspar crystals preserved in sericite and carbonates are recognizable. Laths of feldspar were apparently abundant in the ground-mass of the rock. The numerous rounded and lenticular vesicles present in the section are filled with quartz and a little carbonate, and lined with sericite.

No. J24, Knowle's dyke, adit level, Enoch's Point.—A grey-coloured aphanitic rock in which no minerals are recognizable in hand specimen. The original rock was fine-grained and non-porphyritic, and consisted essentially of small prismatic crystals of hornblende and laths of feldspar, apparently acid plagioclase. Quartz probably was absent. Dusty and granular carbonates and isotropic pennine replace the hornblende and some of the feldspar. Sericite, pyrite, and quartz are present in small quantity. Nomenclature : Hornblende lamprophyre.

No. J20, vesicular dyke, unknown mine, lower adit level, Enoch's Point.—Originally a very fine-grained vesicular rock, in which porphyritic crystals were absent. Apparently the rock was composed almost entirely of microlitic laths of feldspar and hornblende, and possibly some biotite. Quartz is very rare. Ubiquitous aggregates of dusty carbonate and sericite, with a little chlorite and quartz, now replace the rock. The vesicles are filled with quartz and carbonates.

Other narrow dykes of a similar nature which have been sectioned and examined are the Georgia, Little Comet, Cohen's, Argyle (near Jericho), Excelsior (Blue Jacket Creek), Working Miners' (near Kevington), and one from Camp Creek, a branch of the Aberfeldy River.

(*d*) *Gabbro Porphyrites and Basalts.*—The only rocks of this type known to the writer from this belt occur at the Tubal Cain and Eureka mines, and at locality No. 24 on Mr. Herman's map of the Walhalla district (No. 23). The marginal variation of the

Morning Star dyke is also a quartz gabbro porphyrite. Auriferous quartz-veins, which have yielded a moderate amount of gold, occur in these rocks at the Tubal Cain, Eureka, and Morning Star mines.

The Tubal Cain pipe interiorally is a medium-grained granophyric gabbro porphyrite, but the greater part of the intrusion is composed of a dense black rock of basaltic composition. Occasional aplite dykes and veins of epidote, chlorite, carbonate, and quartz, in addition to the auriferous quartz-reefs, intersect the intrusion.

Specimen No. 229, granophyric quartz gabbro porphyrite, Coronation mine, Tubal Cain dyke.—This is a medium-grained melanocratic rock showing porphyritic crystals of augite and occasional biotite flakes and feldspar in hand specimen. A thin section of the rock is composed of abundant large hypidiomorphic phenocrysts of zoned and simply twinned titaniferous brown augite, ragged prisms of much altered biotite which is penetrated sub-ophitically by plagioclase laths in places, and occasional phenocrysts of greatly-altered feldspar in a ground-mass composed largely of interstitial quartz and feldspar in granophyric intergrowth. Hornblende is absent. Ilmenite and leucoxene are common as inclusions in the biotite. Much of the feldspar is highly sericitized, making determination of its character difficult. It appears to be chiefly labradorite, but a little albite now replaces some of it. One phenocryst of untwinned feldspar appears to be orthoclase. Chlorite and a little epidote replace portion of the augite and biotite, and veinlets of chlorite and carbonates traverse the section.

Gabbro porphyrite, marginal variety of Morning Star dyke, near west wall, 300-ft. level.—This is a holocrystalline, porphyritic considerably-altered rock. It differs from the normal diorite porphyrite in that hornblende is rare and augite plentiful, and in the comparative rarity of quartz and the absence of acid feldspar. The augite is a titaniferous variety, occurring mostly in porphyritic phenocrysts often penetrated ophitically by sericitized laths of plagioclase. It is simply twinned, and has a very low axial angle. Basal sections give a figure which is almost that of a uniaxial mineral, and determination of its sign shows it to be +*ve*. It shows maximum extinction angles of 43° from the prismatic cleavage. The stages in the breakdown of the augite are clearly seen. Interlacing veinlets of carbonates traverse it along cleavage planes and other cracks, and marginally its boundaries are often irregular owing to replacement by carbonates. Brown hornblende occurs in places in the section fringing the augite, and a little biotite is also present. The original feldspar was a zoned basic plagioclase, giving maximum extinction angles of 42° from the twin planes, showing it to be bytownite or anorthite. Abundant sericite and a little chlorite and carbonate replace it. Skeletal crystals of ilmenite are common. Sericite and carbonates have been developed on a grand scale, and replace most of the minerals of the original rock, but chlorite is rare.

Granophyric gabbro porphyrite, marginal variety of Morning Star dyke, east wall, No. 3 (400-ft. level).—This section shows more brown hornblende than the previous one, and, in addition, long wisps of bleached biotite, chlorite, and epidote are fairly common. The feldspar is a zoned acid labradorite, with a little orthoclase. The augite has the usual fringe of hornblende surrounding it, and apparently is not so easily chloritized as the hornblende. Quartz is rare except in granophyric intergrowth with feldspar.

Specimen No. 9, porphyritic basalt, lower adit level, Coronation mine, Tubal Cain dyke ; analysis specimen.—In hand specimen this is a dense black rock of basaltic appearance. In thin section it is composed of large hypidiomorphic phenocrysts of brown pleochroic augite in a pilotaxitic ground-mass consisting of sericitized plagioclase laths, chloritized and carbonated granules of augite, a little biotite, and abundant magnetite or ilmenite dust. Veinlets of chlorite and carbonate with a little quartz intersect the rock. The breakdown of the augite has been initiated by veinlets of carbonate which occur along cracks and cleavage planes in the mineral. Patches of chlorite and some dusty carbonates are disseminated through the rock, and a little secondary quartz is also present.

Specimen No. 34, Coronation mine, Walhalla.—It consists of large porphyritic phenocrysts and clusters of crystals of simply and polysynthetically twinned titaniferous augite in a fine-grained mass, consisting of rod-like microlites of greatly sericitized plagioclase near labradorite, traces of biotite, and magnetite dust. Quartz is absent. Chlorite replaces some of the augite.

Specimen No. 223, vein in Tubal Cain dyke.—The vein is composed almost entirely of calcite, chlorite, and epidote in alternate bands, with a little quartz and zoisite. The epidote occurs in hypidiomorphic lemon-yellow crystals, having distinct basal cleavage, and is referable to "pistacite."

An analysis of the Tubal Cain basalt gave the following result. Appended for purpose of comparison is an analysis of an Upper Palæozoic basalt from Mount Wellington.

	1 %	2 %
SiO_2	49.07	49.35
Al_2O_3	14.88	17.61
Fe_2O_3	1.64	1.50
FeO	8.27	9.72
MgO	7.58	3.17
CaO	8.17	7.70
K_2O	1.05	1.56
Na_2O	2.87	3.10
H_2O+	2.21	2.56
H_2O-	0.48	0.65
TiO_2	1.46	2.83
MnO	0.18	0.07
FeS_2	abs.	0.34
P_2O_5	tr.	—
CO_2	2.81	—
	100.67	100.16

1.—Porphyritic basalt, lower adit level, Coronation mine, Tubal Cain dyke; analyst, N. R. Junner. Amer. Class., Auvergnose.

2.—Palæozoic basalt, Moroka snow plains, Mount Wellington; analyst, G. Ampht. (No. 48, p. 267.)

Basalt dyke, locality No. 24 on Mr. Herman's map of the Walhalla district.—A tunnel through this dyke, ostensibly with the view of working quartz reefs (which, according to local miners, occurred on the walls of the dyke), shows it to be a little-decomposed dense black basaltic rock. An aplite vein 2 in. in width intersects the dyke in one place, but the writer saw no signs of quartz-veins.

A thin section of this rock, viewed under the microscope, consists of abundant porphyritic hypidiomorphic phenocrysts of light brown titaniferous augite and smaller and less numerous phenocrysts of altered olivine in a fine-grained ground-mass made up of lath-shaped microlites of labradorite, granules of augite, and dusty ilmenite and magnetite. Feldspar phenocrysts are absent. The augite is often twinned and sometimes zoned. It is relatively free from alteration, but a little chlorite locally replaces portion of it. The olivine is more altered. The usual alteration of this mineral is to talc, with separation of hematite. Occasional veinlets of chlorite traverse the section.

Mr. Herman (No. 23, p. 21) has suggested the possibility that this dyke belongs to the period of the so-called Older Volcanic (? Eocene) lava-flows of the district. Quartz-veins are associated with this dyke, and Mr. Herman further suggests the possibility that deposition of quartz may have continued to Tertiary times. However, the petrological characters of this dyke show clearly that it is closely related to the Tubal Cain basalt, which grades into a granophyric gabbro porphyrite intersected by auriferous quartz-veins and associated with the usual metasomatic alteration characteristic of the Devonian igneous rocks of this belt.

Specimen No. 204, upper tunnel, Eureka mine, near Walhalla.—It is composed of numerous phenocrysts of zoned titaniferous augite—pleochroic, pink to delicate-violet colour—in a holocrystalline fine-grained ground-mass, consisting of rod-like microlites of plagioclase feldspar, augite, and ilmenite grains. In part of the section the rock is coarser grained, and some secondary interstitial micropegmatite is present. The feldspar is greatly sericitized and in part chloritized, and determination of its precise characters is therefore difficult. Chlorite (pennine) is fairly common. It replaces some of the augite. A little dusty carbonate is often associated with it. Leucoxene replaces the bulk of the ilmenite. This rock resembles closely the Tubal Cain basalt.

(e) *Ultrabasic Rocks* (*Peridotite and Perknites*).—These are heavy, lustrous, black rocks in which the femic minerals hornblende, augite, biotite, and olivine reach their maximum development. They occur as lenticular intrusions up to 300 ft. in width, conforming closely to the strike of the strata.

Petrologically, the following types have been recognized:—Hornblende peridotite, near Aberfeldy; hornblende-pyroxene rocks, from Kelly's copper mine dyke, near Walhalla, and from east of Toombon; hornblendites, from Thomson River copper mine and the Shamrock dyke near Wood's Point.

Except in the case of the Aberfeldy peridotite, a little interstitial quartz and alkaline feldspar are always present in these rocks. Small quantities of magmatic sulphides, pyrrhotite, chalcopyrite, and pyrite occur disseminated through them, but in only one case—namely, the Thomson River copper mine—has the percentage of copper justified the working of them.

Numerous assays carried out from time to time at the Mines Department's laboratories have proved the invariable presence of small amounts of platinum in these rocks. Payable auriferous quartz-veins are not found in them, although a little gold appears to be contained in the sulphide impregnations.

Hornblende peridotite, Frenchman's Gully, near Aberfeldy.—Credit for discovering this rock is due to Mr. W. Baragwanath, who located it during his survey of this area. It is a medium-grained black rock showing phenocrysts of hornblende, biotite, and occasionally augite in hand specimens. Coarser-grained varieties exhibit lustre-mottling, due to inclusions of olivine, augite, and biotite in the hornblende.

Microscopically, the rock is composed of abundant olivine and brown hornblende and lesser amounts of biotite, augite, magnetite, and apatite, together with the secondary minerals talc, serpentine, chlorite, and carbonates. Most of the olivine is present in elliptical and rounded grains, probably due to partial resorption by the magma. Frequently it is altered to colourless talc with the separation of magnetite dust, which diffuses outwards in the form of a cloud to the edges of the original crystals. Much of the olivine, however, has altered to yellow and green serpentine, which sometimes shows the characteristic "mesh" structure. The hornblende occurs in ragged phenocrysts micropœcilitically, including olivine, augite, biotite, and apatite. Apart from tremolitic and actinolitic outgrowths and a partial bleaching, it has suffered little alteration. A little chlorite replaces it in part. The biotite occurs in deep brown to almost colourless plates and prismatic laths. It is much bleached, and some serpentine and chlorite and a little carbonate replace portion of it. Colourless hypidiomorphic crystals of augite are not uncommon. They show little or no alteration. Orthorhombic pyroxenes are absent. One chloritized and kaolinized phenocryst of acid plagioclase is present in this section, but other slides show no sign of feldspar. Of the alteration-products, talc, serpentine, chlorite, and magnetite are most abundant. Some coarse crystals of carbonates associated with magnetite are also present.

An analysis of this rock (No. 1, p. 63) gave the following results, viz. :—

	%
SiO_2	41.43
Al_2O_3	5.92
Fe_2O_3	4.03
FeO	7.46
MgO	27.59
CaO	4.31
K_2O	0.64
Na_2O	0.35
H_2O+	6.47
H_2O-	0.32
TiO_2	0.60
CO_2	0.38
MnO	0.42
P_2O_5	0.24
SO_3	nil.
Cl	tr.
Cr_2O_3	0.31
NiO	0.03
CoO	tr.
BaO	nil.
Total	100.50

Special features of this analysis are the very low percentages of silica, alumina, and alkalies which are reflected in the rarity of feldspar and the very high percentages of MgO and H_2O, due to the abundance of talc and serpentine derived from the olivine. No chromium mineral was recognized in thin sections of the rock.

Perknites.—Certain black rocks, having a high specific gravity, and made up almost entirely of hornblende or colourless augite, or both, are found in places in this belt. They contain no olivine or rhombic pyroxene and very little feldspar, and agree, therefore, with Turner's definition of perknite (No. 50, p. 507).

Hornblende-pyroxene rock, Kelly's copper mine, near Walhalla.—This rock occurs as an intrusive pipe in a small gully on the eastern bank of the eastern branch of Stringer's Creek, near Maidentown. At the surface exfoliated boulders of the rock, stained with malachite and azurite, are common. Small quartz-veins, containing threads of yellowish-white asbestos of no economic importance, intersect the rock in places.

Specimen No. 275 is black in colour and coarse-grained. It appears to consist chiefly of black lustrous crystals of hornblende and pale green augite. A thin section of the rock, examined microscopically, is composed almost entirely of colourless monoclinic pyroxene and brown hornblende in approximately equal amounts, and their alteration-products chlorite, talc, and serpentine. A few flakes of chloritized biotite, a crystal or two of highly-sericitized feldspar, and a little ilmenite, magnetite, and apatite complete the rest of the section. Olivine is absent. The hornblende occurs in fairly large euhedral plates, and includes numerous rounded grains of augite, giving a fine example of micropœcilitic structure. Some green hornblende (actinolite) is also present. The normal mode of occurrence of the augite is in relatively small prisms and rounded grains. It gives extinction angles up to 50°, and is often simply twinned.

An analysis made of this rock by the writer gave the following result. Appended for comparison is an analysis of a similar rock described by E. O. Thiele from near Mount Wellington (No. 48, p. 257).

	1	2
	%	%
SiO_2 ..	47.24	51.87
Al_2O_3 ..	6.63	5.28
Fe_2O_3 ..	1.53	2.29
FeO ..	8.05	7.37
MgO ..	18.69	22.52
CaO ..	12.92	8.71
K_2O ..	0.24	0.31
Na_2O ..	0.55	0.47
H_2O+ ..	2.69	0.97
H_2O- ..	0.74	0.17
P_2O_5 ..	n.d.	tr.
MnO ..	0.22	0.10
TiO_2 ..	0.65	tr.
CO_2 ..	abs.	—
Cr_2O_3 ..	0.19	0.21
(NiCo)O ..	0.07	0.21
S	0.09	—
Cu ..	—	0.06
Totals	100.50	100.54

1.—Hornblende-pyroxene rock (perknite), Kelly's copper mine, near Walhalla; analyst, N. R. Junner.

2.—Rock from near Monument Gap, Mount Wellington; analyst, G. Ampt.

The extremely low percentages of alkalies and alumina in the Walhalla rock are in keeping with the extreme scarcity of feldspar in it. The relatively high percentages of MgO and CaO show that the augite and hornblende are rich in these bases. The augite is apparently malacolite, a variety rich in CaO and MgO and poor in Al_2O_3.

Specimen No. 178, hornblende-pyroxene rock, about one mile east of Toombon.—This rock occurs as a lenticular pipe-like intrusion, having a length of about 900 ft. and a maximum width of about 300 ft. It appears to vary in composition from a diorite or gabbro-porphyrite to a hornblende-pyroxene rock, with very little feldspar and quartz. It is locally impregnated with chalcopyrite and pyrite, and stains of malachite and azurite are not uncommon at the surface. In thin section large hypidiomorphic phenocrysts of hornblende and colourless granular lime-rich pyroxene constitute the greater bulk of the rock. A little interstitial albite, quartz and micropegmatite, some accessory apatite and ilmenite, and the secondary minerals chlorite, carbonates, leucoxene, and pyrites complete the section. The hornblende is variously coloured. It is typically brown in the large anhedral plates, and marginally green or colourless. The brown hornblende is often surrounded by a zone of deep sea-green colour, which passes outwards into colourless jagged fibres of tremolite (*vide* microphotograph, pl. III., fig. 7). Occasional hornblende phenocrysts are anomalous, in that they show the form (100) and the absence of the usual form (010) after anthophyllite. Fine micropœcilitic inclusions of augite and ilmenite, and an occasional one of plagioclase, occur in the hornblende. Augite occurs in colourless grains, which are sometimes idiomorphic and simply twinned. The little feldspar that is present appears to be entirely acid plagioclase (albite), exhibiting both albite and pericline twinning. Quartz is uncommon, and appears to be mainly secondary. Chlorite is fairly abundant; it replaces some of the hornblende and augite. Minute grains and veinlets of chalcopyrite and pyrite occur, veining and encrusting the hornblende, augite, and plagioclase of the original rock. They are intimately associated with carbonates and chlorite, and are apparently of the same period of generation.

New Loch Fyne, copper and platinum-bearing dyke.—This rock occurs on the west side of the normal New Loch Fyne dyke. Its characters can best be studied in a crosscut from the main No. 5 adit level. It is here separated from the normal dyke by a narrow band of indurated and metasomatically altered (sericitized and carbonated) sandstone. In hand specimen it is a dense black rock in which flakes of biotite and occasional hornblende crystals are recognizable. Disseminated grains of chalcopyrite, pyrite, and pyrrhotite are common in certain portions of the intrusion, and assays of these mineralized parts have given up to 1.1 % copper and 1 dwt. of platinum. Numerous veins of ankeritic carbonate traverse the rock, but quartz-veins are extremely rare in it. All thin sections examined under the microscope show considerable metasomatic alteration. The original rock appears to have been composed of numerous large irregular-shaped phenocrysts of brown hornblende containing abundant rounded pœcilitic inclusions of biotite, augite, ilmenite, and, less rarely, feldspar, large twisted flakes of biotite, some colourless augite, and a little interstitial feldspar and accessory apatite and iron oxides. Quartz is absent. Veinlets of chlorite and carbonates replace the hornblende along cleavage planes, and black oxides of iron have separated out. Interlaminated lenticles of carbonate occur along the cleavage planes of the biotite, and some chlorite also replaces it in places. Pleochroic haloes are well marked in the chlorite which replaces biotite. Rutile webs are common in certain sections of bleached biotite. One identifiable plagioclase phenocryst in the section is largely replaced by sericite and carbonates, and another one is intersected by numerous more or less parallel veinlets of chlorite associated with a little carbonate (*vide* microphotograph, plate IV., fig. 12). Extremely compact aggregates of carbonates and sericite replace the bulk of the minerals of the original rock.

C.—METASOMATICALLY-ALTERED ROCKS.

(1) *Vein-Alteration.*—The petrological changes brought about by the regional magmatic and propylitic types of alteration have been briefly described in dealing with the diorite porphyrite from the Morning Star dyke (*vide supra*, p. 158), and will be discussed in greater detail in the sequel.

The visible effects of the hydrothermal alteration of the dykes by the vein-solutions are a bleaching of the wall rock, a reduction in the grain of the rocks, and the development in them of pyrite and arsenopyrite. Microscopically, it is seen that practically the whole of the original femic minerals have disappeared, and that much of the feldspar and some of the quartz have been replaced. Carbonates and sericite are extensively developed, and pyrite and arsenopyrite usually accompany them. Sometimes albite and quartz are formed by this alteration.

Specimen No. 78, Morning Star dyke, adjoining Age of Progress reef, Hope adit level; analysed specimen.—The hornblende is replaced in part by a flocculent whitish material resembling kaolin and partly by carbonates. Veinlets of carbonate and sericite traverse this material. Flakes of white mica, with interlaminated carbonates and inclusions of needles of rutile, are secondary after original biotite. The feldspar is largely sericitized and carbonated, and leucoxene replaces the ilmenite, and is in turn replaced by pyrite. Clear quartz and the accessories apatite and zircon and a little micropegmatite remain unaltered. Dusty carbonates and foils of sericite have been extensively developed.

New Loch Fyne dyke, adjoining quartz reef, No. 1 level below No. 5 adit level; analysis specimen.—This is a yellowish-green, fine-grained rock, containing numerous crystals of pyrite disseminated through it. No hornblende or chlorite remains, but a little quartz and micropegmatite have survived the metasomatic alteration. Clear feldspar, chiefly albite, with a little orthoclase, is fairly common in the section. It has probably developed from the original feldspar as a result of the vein-alteration. Leucoxene replaces ilmenite, and is in turn partially replaced by pyrite. Dusty and granular carbonates and aggregates of sericite replace the whole of the femic minerals and much of the feldspar.

No. 18, "Kindly country rock," within 1 ft. from quartz floor, 850-ft. level, A1 mine; analysis specimen.—A rather handsome rock, showing abundant plates of a colourless to light brown mica in hand specimen. No other mineral is recognizable. Under the microscope splendid pseudomorphs of carbonate, with a little sericite after idiomorphic hornblende, are visible. Foils of white mica, with interlaminated carbonates and lenticles of quartz along its cleavage planes, and including the usual "sagenitic webs" of rutile needles, are common. Veinlets of carbonates and sericite intersect the mica. Particularly interesting is the occurrence of numerous clear crystals of albite in the section. in one case showing Carlsbad and albite twinning and giving symmetrical extinction angles of 18° with refractive index less than that of quartz. The albite, although mostly unaltered, is partially secondarily carbonated, indicating that carbonation, in part at least, was later than formation of albite. A little micropegmatite remains in places. Pyrites is not common. Carbonates and sericite are very abundant. An analysis of this rock is given in Part II., p. 188.

No. 7, A1 mine, narrow dyke, close to quartz floor, No. 9 intermediate level; analysis specimen.—In hand specimen, under the microscope, the original rock is seen to have been more acidic than usual. It is fine and very even-grained, and consists for the most part of granular quartz, occasionally idiomorphic, stumpy-shaped prisms and laths of feldspar whose original characters are entirely masked by extensive sericitization, a little iron-magnesian mineral now departed, and fairly abundant needles and prisms of ilmenite. The rock appears to have been a fine-grained aplite dyke. The quartz has been greatly invaded and replaced by sericite and carbonates. Rutile and a little pyrite replace the ilmenite. Carbonates and sericite have been very freely developed at the expense of the minerals of the original rock.

J41, Luck's All dyke, near a quartz reef, lower adit level.—No hornblende or chlorite remains in this section. They are totally replaced by carbonates. Practically all sections of the feldspar, which was andesine with some acid labradorite and a little orthoclase, show signs of alteration, but in general the alteration was not intense, and the specific characters of the feldspar are readily determinable. Its alteration-products are sericite in blades and aggregates of flakes, with some dusty carbonates and a little zoisite. The bulk of the quartz is idiomorphic and little altered. Grains of leucoxene are scattered through the section. Sericite and carbonates in about equal amounts are the main alteration-products of the rock.

No. 37, Little Comet dyke, Wood's Point, adjoining quartz-vein, 220 ft. from surface.—This is a light grey-coloured rock containing abundant crystals of iron and arsenical pyrites distributed through it. It is intersected by a small quartz-vein lined with ankerite. No hornblende or chlorite remains. The idiomorphic outlines are preserved in a doubtful white cloudy material and in part in carbonates. The feldspar, which was albite, has been greatly sericitized. A little quartz, apatite, and sphene remain unaltered. Aggregates of sericite, dusty carbonates, and idiomorphic pyrite and arsenopyrite are common metasomatic minerals.

Contact of quartz-vein and dyke, Evening Star mine, Wood's Point.—This rock resembles the one last described. Albite appears to have been developed in considerable quantity at the expense of the original feldspars, and has in its turn suffered considerable sericitization and carbonation. No femic mineral remains. Quartz replaces some of the carbonate in part of the section, and euhedral pyrite and arsenopyrite are common.

Dyke near quartz-vein, Kelly's Hill mine, Matlock.—This is a greenish-grey rock characterized by the presence of abundant prismatic crystals of silvery mica in hand specimen. Viewed microscopically, the most prominent feature of this rock is the abundant foils and wisps of white mica. They are densely charged with rutile needles, and, normally, are extensively carbonated and occasionally partially replaced by chlorite. No original iron-magnesian mineral remains, although there is a moderate amount of granular and dusty chlorite distributed through the section. Feldspar has entirely disappeared, but its idiomorphic outlines can often be recognized preserved in aggregates of sericite and carbonates. A few relatively-large crystals of leucoxene, showing the characteristic ilmenite parting, are present in the section. Pyrite replaces much of the leucoxene. With the exception of a little apatite, granular and vein-quartz and abundant sericite and carbonates are the only other minerals in the rock, and these constitute by far the greater bulk of it.

Tubal Cain dyke, adjoining a quartz-vein, lower tunnel, Coronation mine, Walhalla.—The original rock was composed of porphyritic phenocrysts of augite and prisms of feldspar in a felted (andesitic) ground-mass, consisting of microlitic laths of feldspar, granules of augite, and abundant dusty grains of ilmenite or magnetite. As a result of the hydrothermal vein-alteration, the augite phenocrysts have been converted into a yellowish, cloudy, nondescript material, and numerous veinlets of carbonate intersect them. Densely packed aggregates of sericite replace all the feldspar, and the ilmenite grains have given place to leucoxene. Little or no quartz occurs in the section, and chlorite appears to be absent.

No. 278, Cohen's dyke, 3075 ft. level, Long Tunnel mine, Walhalla.—A greenish-yellow aphanitic rock traversed by veinlets of quartz. It is composed almost wholly of dense aggregates of flakes of sericite and dusty carbonates, with a little quartz and disseminated pyrite. Several veinlets of quartz and carbonate intersect the rock. Prismatic microlites of what appear to have been hornblende, and which are now chiefly sericite, are common. The sericite flakes have decided parallel arrangement, which imparts a fissility to the rock. The vein-quartz exhibits well-marked comb structure.

Quartz-vein in Cohen's dyke, 2925-ft. level, Long Tunnel mine, Walhalla.—This rock is very similar to the one last described, but pyrite and arsenopyrite are more abundant, particularly close to the vein. Some of the pyrite crystals are fringed with secondary quartz and one pyrite cube replaces vein-quartz. The bulk of the arsenopyrite is in double wedge-shaped crystals.

Dyke, Brohan's reef, "Pinnacles," near Aberfeldy.—This is a yellowish-green aphanitic rock traversed by veinlets of quartz. Small crystals of pyrite are disseminated through it. The original rock consisted of numerous panidiomorphic phenocrysts of feldspar and occasional smaller ones of quartz and biotite in a cryptocrystalline ground-mass. Dense felted aggregates of sericite now replace the feldspar phenocrysts in entirety. White mica replaces the biotite, and sphene or rutile has separated out. Quartz remains little altered. Grains of pyrite and arsenopyrite, the latter occasionally in form of cruciform twins, have been developed in the rock near the veins. Carbonates are absent.

Other dykes examined which have suffered similar carbonation, sericitization, and pyritization in the vicinity of quartz-veins are the Wallaby (near Gaffney's Creek), Georgia, Unknown, Waverly, and the Rose of Denmark.

(2) *Metasomatic Alteration of the Copper-Bearing Dykes.*—Low-grade copper ores—chalcopyrite, cupriferous pyrite, tetrahedrite, and nickeliferous pyrrhotite—occur as impregnations and small veins in certain basic and ultrabasic rocks of this belt—*e.g.*, Thomson River, diorite porphyrite and hornblendite; Toombon

and Kelly's copper mine, hornblende, pyroxene rocks; basic New Loch Fyne dyke, Aberfeldy peridotite, &c. In addition to copper, these ores invariably carry small quantities of platinum, silver, and gold.

The following table shows the result of some assays made of these dykes for the above-mentioned metals by the Mines Department of Victoria:—

Locality.	Ore.	Platinum.	Gold.	Silver.	Copper.
		dwt. gr.	dwt. gr.	dwt. gr.	%
Thomson River Copper mine	Bore cores in dyke	av. 5 0	av. 1 0	av. 8 0	av. 3
New Loch Fyne, Matlock	Mineralized dyke	av. 1 14	av. 1 19	av. 6 17	av. 2.3
Kelly's Copper mine	Mineralized dyke	av. 1 0	av. 0 7	av. 2 3	0.31
Do.	Main dyke mass	0 3	trace	2 0	trace
Shamrock, Wood's Point	Mineralized dyke	0 13	0 3	1 2	1.01
Toombon Dyke	do.	0 4	0 4	1 3	(?)

The sulphides are invariably of later generation than the primary minerals of the original rock. They corrode, penetrate, and encrust the hornblende and biotite in the New Loch Fyne dyke, and replace and encrust the hornblende and feldspar in the Thomson River and Toombon dykes. They appear to be essentially contemporaneous with the chlorite, carbonates, and quartz that are intimately associated with them. Sericite is rare, and, when present, is seemingly of later generation. The sulphides occur normally as impregnations in the dykes, and very rarely as veins, which suggest that they were formed before the igneous rocks had cooled sufficiently to fracture and crack. Their period of formation is believed to belong to the propylitic stage of regional alteration.

The following thin sections of these cupriferous dykes illustrate the type of metasomatic alteration undergone by them and also the paragenetic relations of the sulphide minerals:—

No. 212, ore-bearing dyke, close to west wall, lower tunnel, Thomson River copper mine.—The original rock appears to have been intermediate between a diorite porphyrite and hornblendite. No hornblende remains, although its original idiomorphic outlines are recognizable in the form of pseudomorphs of carbonates and a nondescript yellowish flocculent material. In the alteration of the hornblende, magnetite or ilmenite dust separated out as a black border to the crystals, and was later replaced by chalcopyrite. Isolated relics of highly sericitized and carbonated feldspar and a little quartz and apatite are also recognizable. Dusty and idiomorphic grains of ankeritic carbonate are ubiquitous. The sulphide mineral, which appears to be entirely chalcopyrite, occurs in granular and dust-like form scattered through the section. In every case it is intimately associated with ankerite. In places the sulphide is moulded on and replaces the latter mineral, but in general they are essentially contemporaneous.

In specimen No. 220, from the same mine, the chalcopyrite occurs in granular form associated with carbonate and chlorite and some quartz. It encrusts hornblende and feldspar, and replaces the former mineral and micropegmatite in places.

No. 215, copper-bearing dyke, lower adit level, Thomson River copper mine.—In this rock most of the original minerals have disappeared, and often no trace of their former presence remains. Skeletons of one-time hornblende phenocrysts occur in the form of a white flocculent material greatly veined by carbonates, which latter constitute at least 50 % of the rock. Some chlorite and a little sericite are also present. Chalcopyrite is disseminated through the rock in intimate association with carbonates.

No. 292, ore containing pyrrhotite, stopes above upper adit level, Thomson River copper mine.—Massive pyrrhotite, with a little chalcopyrite, occupy the bulk of the section. The formation of the sulphides was preceded by the development of much chlorite and some carbonate. The pyrrhotite is veined by a copper-coloured mineral which gives reactions in the hand specimens for nickel, iron, and sulphur. Arsenic is absent, and the mineral is therefore apparently pentlandite. It is probably the source of the nickel obtained in the copper matte by the last company who worked this ore.

Another specimen (No. J61) from this mine is highly chloritized, but carbonates are not abundant. Well-developed laths of sericite cut the sulphides which occur in granular and dusty form.

Copper-bearing hornblende-pyroxene rock, 1 mile east of Toombon.—Green hornblende, secondary after the brown variety, and colourless granular augite make up the bulk of this rock. A little interstitial quartz and feldspar and some micropegmatite are also present. The hornblende in the vicinity of the sulphides has been corroded and partially replaced by chlorite, carbonates, and serpentine. Massive carbonates accompany the sulphides, which are mainly pyrrhotite, with a little chalcopyrite and pyrite fringing it. One or two laths of sericite penetrate the pyrrhotite.

No. J22, altered basic, New Loch Fyne dyke, No. 5 adit level.—This rock has suffered considerable metasomatic alteration. The bulk of the hornblende has been replaced by chlorite and a little carbonate. The alteration proceeds along cleavage planes and cracks, resulting in a mesh-like structure resembling that of serpentine after olivine. Apart from bleaching and partial conversion to chlorite, the biotite has suffered no great alteration. Occasional relics of feldspar crystals can be recognized, now veined and replaced by pennine and a little sericite. Some apatite and ilmenite remain little altered. Dense aggregates of carbonates and pennine are very abundant throughout the section. Some secondary sericite, quartz, and large irregular-shaped grains of chalcopyrite are also present. The chalcopyrite is associated intimately with carbonates, and in one place with quartz. Interaction has apparently taken place between biotite and chalcopyrite, resulting in rounding of the latter mineral and the embayment by corrosion of the biotite.

No. J16, carbonate vein carrying tetrahedrite and chalcopyrite in basic New Loch Fyne dyke, No. 5 adit level.—None of the minerals of the original rock, with the exception of a little apatite, remain. Pseudomorphs of chlorite (pennine), with a little carbonate and abundant grains and needles of leucoxene or sphene, occur, replacing hornblende. The characteristic sagenitic webs of rutile and the lath-shaped sections prove the presence of original biotite. It is now replaced by pennine and some carbonate. More than 90 % of the section is composed of carbonates and chlorite. The former predominates over the latter. A little secondary quartz has formed in places. The vein consists mainly of carbonates with a little vein-quartz and some tetrahedrite and chalcopyrite. Carbonates have replaced part of the tetrahedrite.

PART II.—METASOMATISM AND THE GENESIS OF THE GOLD.

1.—METASOMATIC ALTERATION OF THE DYKE ROCKS ASSOCIATED WITH AURIFEROUS REEFS.

As previously mentioned, three main types of metasomatic alteration are recognizable in the auriferous dyke rocks—

- (A) A regional alteration during the final consolidation of the rocks by gases and mineralizers released from the cooling magma. This type of alteration may be sub-divided into—
    - (a) Late magmatic stage.
    - (b) Propylitization.
- (B) An intense post-magmatic hydrothermal alteration of the dykes adjoining the vein-walls.
- (C) Surface decomposition and oxidation by present-day vadose waters.

A.—REGIONAL ALTERATION.

(*a*) *Late Magmatic Stage.*—As a first stage in the regional alteration of the dyke expansions, the ground-mass has been partially re-crystallized in the form of a micropegmatitic intergrowth of quartz and feldspar. Some albite has been developed at the expense of the original feldspars, and secondary quartz is introduced into the rock. The phenocrysts are sometimes in optical continuity with the feldspar of the micropegmatite, as is the case in section No. 81, Evening Star dyke, Wood's Point; and in the Morning Star dyke quartz phenocrysts similarly merge into the quartz of the intergrowth. The bleaching of the hornblende and biotite and the actinolitic and tremolitic outgrowths to the former mineral are also referable to this alteration. In the narrow dykes quartz and albite are sometimes developed as a result of this alteration, but micropegmatite is usually lacking, probably due to their rapid cooling.

(*b*) *Propylitization.*—As a slightly later phase of the same alteration, we get developed the characteristic minerals of propylitization—namely, abundant chlorite after the femic minerals, and sometimes after feldspar; subordinate massive cleaved carbonate, distinct from the dusty type formed by the hydrothermal vein-alteration, inasmuch as it fills interstices between the rock-minerals rather than replaces them*; leucoxene after ilmenite and pyrite and pyrrhotite in turn replace the leucoxene. In addition, epidote and zoisite are often developed, but sericite is unusual. Chlorite variety pennine is the characteristic mineral of this type of alteration. The hornblende, biotite and augite of these rocks are all titaniferous. When hornblende or augite is replaced by chlorite, abundant grains of sphene and occasional needles of rutile separate out from them.

Excellent "sagenitic" webs of rutile are the rule in bleached and chloritized biotite. When the latter mineral is bleached and not chloritized black iron oxides usually separate out from it. The feldspars are occasionally chloritized, and epidote and zoisite replace them in certain cases, but sericite is less frequently developed. Quartz and apatite in general remain unaltered.

Chemical Changes.—In the late magmatic stage silica, alumina, and soda are introduced.

In the propylitic *facies* water, carbon dioxide, and sulphur are added, and occasionally some soda and potash. On the whole, there is no great change in the chemical composition of the rocks affected by this regional alteration.

It is claimed that the regional alteration undergone by these rocks is independent of the vein-solutions, and that the effects of the latter are superimposed upon those of the former. Concisely, the evidence for this conclusion is as follows:—

1. The minerals developed by the regional alteration are just as abundant 3 ft. away from the quartz reefs as they are 20 ft. away from them.
2. There is no mineralogical or chemical transition between the regionally and vein-altered rocks.
3. In one slide of the Morning Star dyke micropegmatite, albite, quartz, and chlorite are penetrated by a veinlet of quartz and carbonates.
4. The micropegmatite, quartz, and carbonates, and sometimes chlorite, fill interstices between the hornblende and feldspar of the original rocks and rarely replace

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* Granular carbonates occasionally replace the femic minerals in part.

these minerals, and in one or two sections there is a suggestion of an intergrowth of quartz and carbonates.

5. Apparently the rocks were not fractured when the regional alteration took place, for the minerals developed as a result of it are uniformly distributed through the dykes, and do not occur in or directly associated with veins. Chlorite, the characteristic mineral of the propylitic *facies* of alteration, practically never occurs in the quartz reefs, and is clearly seen to be replaced by carbonates and white mica in the wall rocks of the veins.

The almost invariable association of propylitization with the dyke rocks strongly suggests a magmatic origin for the gases or solutions causing the alteration. That the magma was a hydrous one is clearly proved by the abundant hornblende, biotite, and apatite—minerals which all require the presence of water for their formation (No. 5).

Hence it is believed that the gases and mineralizers responsible for the above-mentioned alteration had their origin in the cooling magma, and that their escape was made possible by the relief of pressure during intrusion.

Certain acidic dykes—quartz feldspar porphyries—described above (*vide* Part I., p. 152), exhibit a different type of alteration. Felted aggregates of sericite replace the porphyritic feldspar crystals, the biotite is bleached, and the ground-mass has been sericitized and partially silicified, and pyrites has been developed in small quantities. Carbonates are rare or absent, likewise chlorite, probably because of the paucity of the ferromagnesian minerals in the rock rather than the chemical nature of the mineralizers.

The ultimate product of this type of alteration is a rock composed of quartz, sericite, and pyrite, of the Diamond Creek dyke type (No. 27, p. 339). The extensive sericitization suggests a lower temperature alteration than the propylitization.

B.—HYDROTHERMAL ALTERATION ADJOINING THE VEIN-WALLS.

Adjoining the veins, for varying distances usually less than 1 ft., the dyke rocks have been bleached and rendered much finer-grained. Scattered crystals of pyrite and arsenopyrite normally are the only minerals recognizable in hand specimens of these altered rocks. The sulphides are most abundant near the vein-walls, and decrease in amount outwards from them.

(*a*) *Chemical Changes.*—The following analyses show clearly the nature and the trend of the alteration :—

	1	2	3	4	5	6	7	8
	%	%	%	%	%	%	%	%
SiO_2 ..	49.65	39.92	48.47	44.45	48.06	42.73	56.91	7.42
Al_2O_3 ..	16.73	14.81	17.50	16.17	19.86	10.86	13.31	—
Fe_2O_3 ..	0.31	0.61	0.61	1.95	0.54	0.60	0.08	—
FeO	8.99	5.81	8.55	6.62	7.52	6.46	5.33	5.31
MgO ..	5.88	6.80	4.51	3.70	3.13	10.14	3.66	3.47
CaO ..	7.87	8.28	8.41	4.98	6.86	6.16	3.38	3.35
K_2O ..	0.80	3.51	1.23	2.76	0.99	1.80	3.76*	—
Na_2O ..	3.10	1.41	2.73	2.57	3.96	1.84	—	—
H_2O+ ..	2.50	1.03	3.10	1.68	2.21	0.81	1.19	—
H_2O- ..	0.14	0.23	0.07	0.31	0.30	0.28	0.13	—
CO_2	1.08	16.38	0.90	11.23	3.33	16.05	9.75	—
TiO_2 ..	2.81	1.26	2.45	2.10	1.82	1.22	1.40	—
MnO ..	0.14	0.09	tr.	0.15	0.12	n.d.	0.23	0.22
P_2O_5 ..	0.04	—	0.32	0.70	0.10	n.d.	abs.	—
Cr_2O_3 ..	—	—	—	—	0.03	—	—	—
NiO. CoO ..	tr.	tr.	nil	nil	tr.	—	—	—
BaO ..	—	—	—	—	0.05	—	—	—
SO_3 ..	—	—	nil	tr.	—	—	—	—
Cl ..	—	—	tr.	tr.	—	—	—	—
FeS_2 ..	n.d.	st. tr.	0.81	0.93	0.92	0.54	0.85	—
Totals ..	100.04	100.14	99.66	100.30	99.80	99.49	99.98	—

1.—Propylitized diorite porphyrite, Morning Star dyke, 10 ft. from Cherry's reef, Hope adit level; analyst, N. R. Junner.

2.—Vein-altered diorite porphyrite, Morning Star dyke, with 1 ft. of Cherry's reef, Hope adit level; analyst, N. R. Junner.

3.—Propylitized diorite porphyrite, New Loch Fyne mine, 5 ft away from quartz “ floor,” No. 1 level below No. 5 adit level ; analyst, F. Moss.

4.—Vein-altered diorite porphyrite, New Loch Fyne dyke, from within 1 ft. of same “ floor ” as in No. 3 ; analyst, J. C. Watson.

5.—Propylitized hornblende mica lamprophyre, A 1 mine; 10 ft. from quartz “ floor,” 850-ft. level ; analyst, N. R. Junner.

6.—Vein-altered hornblende mica lamprophyre, A 1 mine, “ kindly country-rock ” of the miners, adjoining quartz floor, 850-ft. level ; analyst, N. R. Junner.

7—Vein-altered A 1 dyke, close to quartz “ floor,” No 9 intermediate level, A 1 mine ; analyst, N. R. Junner.

8.—Extract from No. 7 above by dilute HCl at boiling temperature. 7.42 % = total SiO_2, Fe_2O_3, Al_2O_3, &c , extracted. Analyst, N. R. Junner

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* Nearly all K_2O.

In all cases it is seen that SiO_2, H_2O, and TiO_2 have been considerably leached, also part of the FeO and Al_2O_3, and in two cases there is a marked reduction in Na_2O. The large reduction in the H_2O percentage is explained by the replacement of chlorite by carbonates and sericite. Potash has been increased considerably owing to the replacement of the soda-lime feldspars by sericite. In the Morning Star and A 1 rocks the magnesia percentage has been increased. In these same rocks the percentage of lime remains fairly constant, but in the New Loch Fyne it is considerably reduced.

The large increase in carbon dioxide is a result of the fixing of the bases CaO, MgO, MnO, and part of the FeO as ankerite. Comparison of analyses 7 and 8 show that practically the whole of these bases are in the form of carbonates. Furthermore, the amount of CO_2 required to fix the whole of the CaO, MgO, FeO, and MnO in analysis 7 is 9.82 %, which very closely approaches the amount determined by analysis—*i.e.*, 9.75 %.

If we consider the whole of this carbonate as being of uniform composition, then it has the approximate formula—

$$4\ CaO,\ 5\ (FeMn)O,\ 6\ MgO,\ 15\ CO_2.$$

In analysis 2 the theoretical percentage of CO_2 required to satisfy the whole of the above-mentioned bases is 17.89, while the amount determined by analysis is 16.38 %, showing that the bulk of the FeO, MgO, CaO, and MnO have been used up to form carbonates. In this rock some leucoxene and plagioclase feldspar containing CaO remain, explaining the excess of the bases.

In the New Loch Fyne case the amount of CO_2 necessary to fix the same bases as carbonates is 12.12 %. However, some apatite and leucoxene remain in the rock, explaining the excess of 0.89 % CO_2. The reversal of the alkalies is not so complete in analyses 4 and 6 as in the Morning Star example. The reason is that some fresh albite has been developed in the New Loch Fyne and A 1 dykes as a result of the vein-alteration.

Analysis 7 appears anomalous in some respects. Microscopical examination of a thin slice of the rock, however, shows that it is the vein-altered *facies* of a rock much more acid than the normal A 1 hornblende mica lamprophyre. It probably represents an altered vein in the normal dyke.

(*b*) *Mineral Changes.*—As a result of the hydrothermal vein-alteration, the femic minerals hornblende and chlorite have been the first to break down. Near the veins they are completely replaced. Where the hornblende has been previously chloritized it gives rise to cabonates with or without sericite, and a little quartz. In many cases, however, the hornblende has not been chloritized prior to the attack by the vein-solutions. In such cases it is, in part, converted to a white or cream-coloured flocculent material, probably a hydrous aluminium silicate. In the process most of the FeO, MgO, and CaO have been leached and re-deposited in the form of ankerite, which almost invariably accompanies this (?) mineral. This description of the alteration of the hornblende applies equally well to augite, but the trend in biotite is usually in a different direction. In the regional alteration of this mineral it may either be replaced by chlorite, and possibly epidote, with the separation of rutile, or be bleached. As a result of the vein-alteration the chlorite and epidote are replaced by carbonates for the most part, and sometimes lenticles of quartz have formed along the cleavage planes. The bleached biotite, on the other hand, gives rise to white mica, with interlaminated carbonates and a little quartz.

Leucoxene and granular sphene replace the whole of the ilmenite, and they are, in turn, frequently replaced by idiomorphic pyrite and arsenopyrite, and sometimes by carbonates. Normally, the feldspars become highly sericitized, but often albite is developed as a result of the vein-alteration—*e.g.*, in the New Loch Fyne, A 1, Rose of Denmark, Evening Star, and Working Miners' dykes. In such cases it is also generally present in the adjoining quartz-veins. Furthermore, albite is often developed in the process of replacement of the dyke wall rock by the vein-quartz, as in the Morning Star, Rose of Denmark, and Working Miners' mines. Carbonates partially replace the feldspars in certain cases, and a little secondary quartz is sometimes formed at the same time.

The only stable minerals are quartz and apatite, and their stability is only relative, as they sometimes suffer attack and replacement. Of the secondary minerals, dusty carbonates and flakes of sericite are most abundant. Frequently they comprise more than 50 % of the altered rock. The intensity of carbonation appears to vary in a general way with the basicity of the rock. Carbonates are absent in certain vein-altered quartz porphyries from Brohan's reef, junction of Jordan and Thomson Rivers, &c., while in the altered ultra-basic rocks—*e.g.*, New Loch Fyne dyke—they sometimes constitute more than 50 % of the rock. Sericite, on the other hand, is extensively developed in the acidic types, and is not so abundant in the altered basic and ultra-basic rocks. Another peculiar feature is that pyrite is often more abundant in the sericitized rocks than in the highly carbonated ones.

The calculated approximate mineral compositions of some of these vein-altered rocks are given in the accompanying table :—

——	1	2	3
	%	%	%
Sericite[*]	29.75	23.40	40.00
Ankerite	35.82	25.54	22.20
Albite	11.92	21.72	—
Quartz	16.30	16.70	35.40
Anorthite.. ..	2.86	—	—
Rutile	—	1.79	1.40
Leucoxene ..	3.09	0.77	—
Apatite	—	1.54	—
Pyrite	—	0.93	0.85
Kaolin	—	4.50	—
Excess Al_2O_3 ..	—	1.14	—
Fe_2O_3	0.61	1.95	0.08
	100.35	99.98	99.93

1.—Vein-altered diorite porphyrite within Morning Star dyke, with 1 ft. of Cherry's Reef, Hope adit level.

2.—Vein-altered diorite porphyrite, New Loch Fyne dyke, from within 1 ft. of quartz "floor," No. 1 level below No. 5 adit level.

3.—Vein-altered A 1 dyke close to quartz "floor," No. 9 intermediate level, A 1 mine.

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[*] Theoretical muscovite.

The following table sums up the progressive changes in the mineral composition of these rocks as a result of the magmatic, propylitic and vein-alteration undergone by them.

Magmatic Minerals.	Magmatic Alteration.	Propylitisation.	Vein-Alteration.
Hornblende	Actinolitic and tremolitic outgrowths and partially bleached	1. Hornblende	1. (?) Yellowish-white flocculent material and carbonates
		2. Chlorite with a little carbonate; separation of sphene	2. Carbonates and sericite and a little quartz
		3. Chlorite and magnetite, pyrite	3. Carbonates and pyrite
Augite	Augite	1. Augite	1. Carbonates and cream-coloured flocculent material
		2. Chlorite and serpentine	2. Carbonates and sericite
Biotite	Bleached in part	1. Bleached, rutile and magnetite separate	1. White mica, carbonates, quartz and rutile, pyrite after magnetite
		2. Chlorite and a little epidote, rutile and magnetite separating out	2. Carbonates and white mica and rutile wisps
Plagioclase	Albite in part	1. Albite	1. Albite, sericite and carbonates
		2. Chlorite and a little carbonate	2. Carbonates
		3. Sericite rare	3. Sericite
Orthoclase	Orthoclase	1. Little chlorite, sericite and carbonates	1. Sericite, carbonates and a little quartz
		2. Epidote and zoisite	2. Carbonates
Ilmenite	Ilmenite	Leucoxene, pyrrhotite and pyrite	Sphene, carbonates and pyrite
Quartz (?)	Interstitial quartz formed	Quartz	Partial replacements by carbonates and sericite
	Interstitial micropegmatite quartz & albite	Interstitial carbonate	Very little micropegmatite remains

(*c*) *Summary of Effects of Alteration by the Vein-Solutions.*—The holocrystalline medium to coarse-grained melanocratic rocks of the propylitic *facies* are converted into yellowish-green aphanitic rocks impregnated with pyrite and arsenopyrite.

Chemically, CO_2 and K_2O have increased greatly and MgO slightly. Na_2O, SiO_2, and H_2O have been markedly reduced, and TiO_2, FeO, and Al_2O_3 partially leached.

The microscope shows that, with the exception of apatite and some of the quartz, all the minerals of the original rocks have succumbed to the intense chemical action of the alkaline carbonate vein-solutions and have been replaced, for the most part, by ankeritic and dolomitic carbonates and sericite, usually with some quartz, albite, pyrite, and sphene and rutile.

Chlorite (pennine), the characteristic mineral of the propylitized rocks, entirely disappears close to the vein walls, and apparently is unstable under the action of the vein-solutions. Sericite, which is rare in the propylitized rocks, is extremely abundant in the vein-altered ones. The carbonates of the propylitic *facies* are massive and cleaved, and fill interstices between the rock-minerals, while those of the vein-altered wall-rocks are dusty and granular, and occur replacing the same minerals. The progressive stages in the replacement of the minerals are extremely well illustrated in thin sections of these rocks. As usual, the femic minerals in the order hornblende, biotite, augite, are the first to disappear. Alteration starts along microscopic cracks and cleavage planes in these minerals, and rapidly spreads inwards. Fine pseudomorphs of carbonates and sericite after idiomorphic hornblende, augite, and biotite can often be recognized.

The effects of the regional, magmatic, and propylitic alterations are, in the main, constructive. Much of the micropegmatite, quartz, albite, carbonates, and pyrrhotite which are formed at this stage fill interstices in the rocks.

Destructive metasomatic replacement is largely confined to chloritization and the formation of leucoxene, with the development of a little carbonate, epidote, pyrite, and sericite. The hydrothermal alteration, on the other hand, as has been shown, is intensely destructive.

There seems every reason for believing that the attacking solutions in both cases were of similar composition—*i.e.*, rich alkaline carbonate solutions. What, then, is the cause of the difference in their effects? The results of Konigsberger's and Müller's experiments indicate a possible explanation (No. 30, p. 569). According to these workers, the attack of alkaline carbonate solutions on various rock-forming minerals appears to become considerable at those temperatures at which they become strongly hydrolyzed, and that free CO_2 diminishes the activity of the alkali. They showed that quartz, muscovite, and adularia were dissolved completely in a 20 % solution of Na_2CO_3 at 350° C., and that water containing both CO_2 and Na_2CO_3 had very little action on quartz, adularia, muscovite, sphene, biotite, &c., at 370° C.

It seems reasonable to expect that free CO_2 would be present at the higher temperatures of the regional magmatic and propylitic alterations, which would explain their minor destructive effects. The vein-solutions, on the other hand, probably contained little or no free CO_2, and their temperature was such that they were strongly hydrolyzed, resulting in the intense destructive metasomatic alteration of the wall-rock.

C.—NOTES ON CERTAIN MICAS OF METASOMATIC ORIGIN.

White micas, containing abundant inclusions of needles of rutile and often interlaminated carbonates, are common in the metasomatically-altered dyke rocks of this belt. It was at first thought that they were ordinary muscovite or sericite, but chemical and microscopical examination has proved without doubt that most of them are bleached and carbonated biotite.

Silvery flakes of mica were isolated from the Kelly's Hill dyke, near Matlock, and subjected to examination. Under the microscope basal sections showed some carbonates and abundant "sagenitic" webs of rutile. Some of the mica was treated with acid to remove the carbonates and then examined under convergent polarized light. A black cross, which hardly divided on rotation, was obtained with certain flakes, and in all cases the optical axial angle was small compared with flakes of muscovite of approximately equal thickness.

A chemical analysis of the impure mica, and also a partial analysis of the extract by dilute hydrochloric acid at the boiling temperature of water, gave the following results, viz.:—

	1	2
	%	%
SiO_2	35.32	—
Al_2O_3	13.72	—
Fe_2O_3	0.55	—
FeO	6.99	5.45
MgO	7.65	3.96
CaO	9.53	9.33
K_2O	3.93	—
Na_2O	1.12	—
H_2O+	2.59	—
H_2O-	0.67	—
CO_2	14.95	—
TiO_2	3.72	—
MnO	—	—
P_2O_5	abs.	—
Total	100.74	

1.—Impure white mica in vein-altered dyke, Kelly's Hill mine, near Matlock Analyst, N. R. Junner.

2.—Extract from "1" with dilute HCl at boiling temperature. Analyst, N. R. Junner.

The ratio of silica to alumina, combined with the relatively high percentage of TiO_2, suggests at once that this mica belongs to the biotite class, and this belief is strongly supported by the abovementioned optical examination of it.

A similar white mica separated from the vein-altered A 1 dyke (specimen No. 18, analysis No. 6—*vide supra*, p. 188) gave 2.8 % TiO_2 on analysis, confirming the presence of rutile, which is seen in sagenite webs under the microscope. Biotite has been noted in the propylitic *facies* of the A 1 dyke, and, without doubt, the white mica is the bleached form of this mineral.

Other metasomatic white micas of a similar kind occur in the altered Rose of Denmark, Alabama, Ten-Mile, New Loch Fyne, and Waterloo Gully dykes.

The presence or absence of included needles of rutile in these micas is a useful criterion in determining their original characters.

Hand specimens of certain highly carbonated basic rocks—*e.g.*, New Loch Fyne, Hunt's, and the A 1 dykes—often contain small patches and spots of an apple-green coloured mineral. Examined microscopically, this mineral is seen to occur in colourless or light green coloured wisps and laths. It is slightly pleochroic in some sections, and its polarization colours are high, approaching those of muscovite, which distinguishes it at once from chlorite, and suggests that it is either chrome or vanadium mica.

A partial analysis of a highly-carbonated green-coloured variety of the New Loch Fyne dyke, from No. 5 adit level, gave 0.29 % Cr_2O_3, and failed to detect any V_2O_3. A thin section of the rock examined under the microscope showed the presence of flakes of a light green pleochroic mica in addition to sericite, carbonates, rutile, and quartz. Consequently, there can be little room for doubting that the Cr_2O_3 is resident in the green mica. To discover whether or not the Cr_2O_3 had been introduced in the hydrothermal solutions, an analysis was made of the least-altered dyke from the same vicinity for Cr_2O_3. The result, 0.23 % Cr_2O_3, indicates that the chromium was originally present in the rock.

2.—Origin of the Vein Conduits in Dykes.

A.—CONTRACTION, JOINTING, AND FAULTING.

Several views have been expressed as to the origin of the vein-channels in the dykes.

According to H. Thompson (No. 49, p. 246), "The flat veins of quartz in the diorite dykes do not penetrate to any great depth, and are really detached strings of quartz having no connection with one another."

Phillips (No. 39, p. 643) claimed "that the origin of the 'floors' was due to the filling of cracks near the surface by secondary solutions due to the breaking down of auriferous pyrites."

Mr. O. A. L. Whitelaw (No. 55, p. 13) regarded the quartz reefs as filling contraction-fissures in the dykes caused by the drying and cooling of the plastic dyke-mass.

W. Lindgren (No. 31, p. 134) has expressed a doubt that the last-named explanation is the correct one in the case of the reefs in the Morning Star dyke.

The writer's own study of the question has convinced him that two factors—contraction-jointing and orogenic movements—have led to the formation of the greater bulk of the vein-channels.

In the narrow dykes he is of the opinion that many of the veins fill contraction joints. The evidence for this view is as follows:—

(1) The quartz-veins in these dykes frequently occur in form of flat, apparently disconnected "ladder veins," which usually end abruptly at the dyke walls.

(2) Where the reefs continue out into the country-rock they soon fray out and disappear.

(3) Prismatic jointing is common in many of these dykes.

As previously mentioned, many, if not most, of the reefs in the dyke expansions occur in faults. However, prismatic jointing parallel to the main reefs is particularly well developed in certain of these dykes—*e.g.*, Morning Star, A 1, and New Loch Fyne. Infilling these joints in practically every instance are embryonic veins—threads of quartz and carbonate which are sometimes auriferous, and which rarely exceed one quarter of an inch in thickness. Similar joints, containing veinlets of quartz, occur in the strata in the immediate vicinity of the dykes in some cases. It is probable that the original jointing of these dyke expansions was determined by contraction, and that movement occurred along these planes prior to the introduction of the quartz.

On the other hand, numerous instances have been noted of reefs occupying strike-faults which are quite independent of contraction-jointing (*vide supra*, p. 145).

B.—REPLACEMENT.

A study of thin sections of many of the reefs occurring both within dyke rocks and within Silurian slates and sandstones indicates that they have been formed in part by the gradual metasomatic replacement by quartz of the wall-rock surrounding small cracks and fissures.

In reefs in the strata a laminated or brecciated character is the rule—*e.g.*, Cohen's Creek, Harbinger, Fulton's, Bismarck, Sailor Bill, Ten-Mile, and numerous others. Thin slices of these reefs examined microscopically show that the brecciated fragments of the wall rock have been partially replaced by quartz, albite, pyrite, and sericite. Some sections show the complete replacement of the included fragments by interlocking grains of quartz and dusty pyrite and the separation of black opaque rock residues. The laminations are composed chiefly of granulated quartz, pyritized films of the wall-rock, and finely-divided pyrite and arsenopyrite.

Many of the reefs within the dykes have been enlarged by the replacement of the dyke wall-rock, as will be seen from the following examples:—

Specimen No. J5, auriferous vein-quartz, 400-ft. level, Morning Star mine.—Included fragments of the dyke wall rock are present in this section. They are replaced for the most part by granular quartz and prisms and laths of clear albite. Sericite and pyrite and a little carbonate are also present. The boundaries of the inclusions merge gradually into coarsely crystalline vein-quartz. A further stage in the replacement is seen in places in the same slide. A mosaic of irregular-bounded interlocking grains of quartz associated with some yellow leucoxene and rutile, dusty rock residues, and a little finely-divided pyrite, are all that remain of the inclusions.

Specimen No. 11A, rich floor, No. 9 intermediate level, A 1 mine. —The greater bulk of the quartz in this portion of the reef is of replacement origin. Former brecciated fragments of the wall rock are now converted into aggregates of granular quartz and dusty pyrite. Much of the pyrite occurs in parallel lines or laminations associated with opaque rock residues and replacing the latter.

Specimen No. J7, stopes below No. 9 level, A 1 mine.—Two types of quartz are present in this section—

(1) Coarse vein-quartz, often idiomorphic, and exhibiting comb structure in places. Some bournonite is present in this quartz, but no gold.

(2) Finely-granular anhedral quartz admixed with abundant dusty and granular pyrite and a little leucoxene close to the vein-walls.

Specimen No. J7B, stopes below No. 9 level, A 1 mine.—Numerous skeletons of included slate fragments partially replaced by quartz, chlorite, carbonates, sericite, and dusty pyrite are present in this section. In nearly all cases the chlorite fringes the inclusions. The bulk of the quartz is of the ordinary vein-type.

No. J10, contact of vein-quartz with dyke, No. 6 level below main adit level, Rose of Denmark mine.—The sericitized and carbonated dyke wall rock has been extensively replaced by a granular quartz mosaic with some carbonate and sericite and pyrite. Traces of leucoxene, apatite, sericite, rutile, pyrite, and arsenopyrite remain from the original rock. The bulk of the sericite has been replaced by albite and quartz, and the dusty carbonates have given place to a more massive type. The vein consists of albite, carbonate, and quartz, and represents a further stage in the replacement.

This specimen has been subjected to considerable pressure, as is proved by the curved and fractured laths of albite and carbonate, and by the strain polarization and granulation of the quartz.

No. J15, contact of dyke, vein-quartz, and included slate fragments, main adit level, Working Miners' dyke, Kevington.—Skeletons of former dyke inclusions in the quartz-veins are present in form of mosaics of interlocking quartz grains with a little finely-divided pyrite. Pellucid albite has been developed round these inclusions. The slate fragments, in which detrital grains of blue tourmaline and colourless zircon are common, have been greatly sericitized and carbonated, and in places replaced by quartz, clear albite, and dusty pyrite. The latter mineral appears to be replacing residual rock dust for the most part.

As in the previous example, effects of pressure are evident in the twisting of the laths of albite, strain polarization in the quartz, and in the fracturing of the grains of pyrite and arsenopyrite. Carbonates fill the fractures in the sulphides.

No. J42, dark-coloured auriferous quartz, wall of No. 2 reef, stopes from No. 2 level below main adit level, New Loch Fyne mine.—By far the greater part of the quartz is replacing dyke material. The process of replacement has reached an advanced stage, although numerous sericitized and carbonated inclusions of the dyke wall-rock, partially replaced by quartz, can be recognized. Grains of pyrite and tetrahedrite (?) are scattered through these inclusions and also through the quartz, giving to it the dark colour seen in hand specimens. Some fresh albite is visible in places, and much of the quartz appears to be replacing this mineral, whose prismatic shape and cleavage it has retained. Relics of leucoxene and rutile are not uncommon in the rock. The gold occurs in minute grains deposited on pyrite and tetrahedrite (?), and in one place on carbonates and veining quartz in a partly replaced fragment of dyke. An irregular lamination, consisting of finely-divided pyrite and tetrahedrite associated with some ankerite, traverses the vein. Effects of pressure are noticeable in the strain polarization and granulation of the quartz.

Laminated quartz, stopes above No. 2 level below main adit level, New Loch Fyne mine.—Two distinct laminations are present in this section. One of them is composed chiefly of carbonates, and is traversed by a narrow veinlet of arsenopyrite, pyrite, and jamesonite (?). The other consists of granular arsenopyrite, pyrite, and jamesonite (?), which latter mineral occurs in silvery-grey, vertically striated prisms and needles, and in massive form, replacing pyrite in part. The laminations are not of replacement origin. They appear to be slip-planes or minute fractures in the quartz. The bulk of the latter mineral is of the ordinary fissure-filling type.

C.—FISSURE-FILLED VEINS.

On the other hand, there is abundant evidence that much of the quartz has been deposited from solution in open spaces. Comb structure—prisms of quartz, carbonates, and sometimes albite projecting from the vein-walls—is well developed in many reefs in dykes—*e.g.*, Little Comet, Hunt's, New Loch Fyne, Blue Jacket, A1, &c. In many cases—*e.g.*, Evening Star dyke, Wood's Point—prisms of quartz, pyramidally terminated, project inwards from each wall of the vein, leaving an open space between the crystals.

Drusy cavities or vugs, sometimes of large size, are common in many of the reefs in the dyke bulges—*e.g.*, Evening Star, New Loch Fyne, Eldorado, A 1, &c. Coarsely-crystallized quartz, dolomite, and calcite occur in these cavities. The loosely crystalline character of the quartz in certain reefs is also suggestive of fissure-filling.

Both replacement and fissure-filling may occur in the same reef within a few feet of one another.

For instance, the rich, narrow, laminated reef of replacement origin worked at present by the New Loch Fyne Company between No. 1 and No. 2 levels, below the main adit level, passes in places into a wide, poorly auriferous reef in which the laminated structure is absent. The quartz shows comb structure, and is in part crystalline and vuggy.

3.—The Origin of the Gold.

The following views have been expressed at various times as to the origin of the gold in the reefs of this belt.

Mr. H. A. Thompson (No. 49, p. 248), dealing with the Wood's Point reefs, claimed that the mineral contents of the veins were derived from the rocks bounding them. He further states that

"Near the surface these dykes are much decomposed, and in this condition the quartz veins traversing them have yielded large quantities of gold; but as the rock becomes hard and compact at a greater depth the gold in the veins decreases, indicating that this decomposition of the bounding rock and the consequent liberation of the contained gold was necessary to the aggregation of the latter in the quartz veins. The dyke may contain quite as large an amount of gold where the quartz veins are worthless as it does where they are rich, but it will require long ages to pass over them before the necessary changes are affected that would render the gold available."

According to Mr. R. A. F. Murray (No. 34, p. 70), the general appearance of the reefs in this district is greatly in favour of the theory that the quartz-veins and the contained metals and minerals were segregated from the surrounding rocks into cracks and fissures.

In his "Geology of Victoria" (No. 35, pp. 122 and 123), Mr. R. A. F. Murray quotes the late Dr. Howitt's view that the gold of our reefs came from the sea water of Silurian times, and was later collected together by hot solutions from granitic magmas.

Mr. Mennell (No. 33, p. 396), in his description of the Morning Star dyke, suggested that the gold came from minute quantities of gold present in the adjoining sediments and was re-deposited in the quartz-veins by the action of heated acid waters connected with the intrusion of the dyke.

Let us now examine these and other theories usually advanced to account for the origin of the gold, and see how far they conform to the facts.

1.—The gold was deposited with the Silurian sediments and was later collected and concentrated by hot ascending waters.

Dr. A. W. Howitt and Messrs. R. A. F. Murray, E. J. Dunn, and T. S. Hart have supported this theory. To test it, Dr. Don (No. 10, p. 568) analyzed the country-rock (slates and sandstones) from the deeper levels of the Long Tunnel mine, Walhalla, at various distances from the lode. His results showed that no gold exists in the sedimentary rocks away from the quartz-veins and dykes, and that a marked inverse ratio exists between the auriferous contents and the distance from the lode.

Furthermore, this theory receives no support from the mode of occurrence of the gold.

2.—The gold was originally present in the minerals—*e.g.*, hornblende, augite, and biotite—of the dykes.

In numerous localities in Australia and New Zealand auriferous quartz-veins occur in or directly associated with igneous rocks rich in hornblende — *e.g.*, Kalgoorlie (W.A.), Hauraki (New Zealand), Charters Towers and Mount Morgan (Queensland), Walhalla, Wood's Point, Dargo, Rheola (in Victoria); and, according to Mr. Pittman (No. 40, p. 62), "In every case in New South Wales where auriferous reefs are associated with granite the latter is hornblendic." Exotic occurrences of a similar nature are very common—*e.g.*, Transylvania, Comstock, Juneau (Alaska), &c.

Numerous writers have claimed that the gold in these deposits was originally present in the hornblende and other minerals of the igneous rocks.

G. F. Becker (No. 4, p. 224) has suggested that the repository of the silver and gold of the Comstock lode was the augite and other iron-magnesian minerals of the diabase country-rock.

Prof. F. W. Hutton (No. 26, p. 272), speaking of the Hauraki goldfield, says:—"There is no reasonable doubt that the gold came from out of the volcanic rocks, and was not brought into them from below."

B. von Inkey (No. 51) believed that the hornblende, augite, and possibly biotite were the source of the precious metals found in the Transylvanian andesites and dacites.

C. G. Gibson (No. 42, p. 29) suggests that at Kalgoorlie the gold was originally present in the iron-magnesian minerals of the greenstones, and on their alteration to chlorite the gold was released.

F. R. Feldtman (No. 14, p. 91), however, expresses a doubt that this explanation is the correct one.

H. A. Thompson (No. 49, p. 248) claimed that at Wood's Point the mineral contents of the veins were derived from the rocks bounding them.

To test this theory at Walhalla, Dr. Don (No. 10, p. 575) made comprehensive analyses of—

(1) Cohen's dyke, containing no sulphides, and not associated with an auriferous quartz reef.
(2) Cohen's dyke, associated with such reefs.
(3) Hornblende separated from Cohen's dyke and the Thomson River copper mine dyke.

His results indicate that when no quartz is associated with Cohen's dyke the rock contains little or no sulphides, and is non-auriferous; that where the dyke is associated with quartz, but the quartz is not auriferous, the dyke is likewise barren; that the percentage of sulphide in the dyke is greatly increased when it is associated with highly pyritiferous quartz, and that in this case the dyke sulphides are auriferous, though much less than those of the associated reefs; and that not a trace of gold is present in the hornblende (No. 10, p. 652).

Thanks to the courtesy of Mr. M. Copland, the following assays were made for the writer by Mr. H. R. Murphy, lecturer in assaying at the School of Mines, Ballarat, of propylitized and vein-altered rocks from the vicinity of Wood's Point and Gaffney's Creek :—

No. 24.—Propylitized mica hornblende lamprophyre, A 1 mine	No gold detected
No. 67.—Propylitized diorite porphyrite, 400-ft. level, Morning Star mine	No gold detected
No. 7.—Vein-altered dyke containing a little pyrites, No. 9 intermediate level, A 1 mine ..	No gold detected
No. 135,—Vein-altered dyke with very little pyrites, Hunt's mine	No gold detected
No. 46.—Vein-altered dyke containing a good deal of pyrites, Hope adit level, Morning Star mine	3.5 gr. of gold per ton

These results suggest that there is no gold inherent in the propylitized rocks away from the quartz-veins, and that gold is only present in the vein-altered types when pyrites is present.

The following field and petrological evidence supports Dr. Don's conclusions that the gold has not been derived from the hornblende or other minerals of the dyke rocks associated with the reefs :—

(1) The history of mining in this belt has shown that the most payable reefs occur in association with dyke rocks of intermediate to basic composition, and that quartz-veins associated with the more acid and more basic types have yielded little gold. If we accept as a premise that the dykes are consanguineous, then it would appear that the origin of the gold is a factor of the differentiation of the dykes.

(2) We should expect that the metasomatically altered rocks which were originally very rich in hornblende and other iron-magnesian minerals, such as the Aberfeldy peridotite, hornblendite from Thomson River copper mine, and Shamrock's dyke, Wood's Point, should be associated with rich gold values. The reverse is the case. These dykes contain copper, platinum, and silver in small quantities, but gold is usually lacking or present in very small amounts.

(3) The theory does not explain the occurrence of gold in the quartz-veins in the sedimentary rocks outside the dyke belt.

(4) The unaltered or slightly altered dyke rocks should be richer in gold than the highly metasomatically altered ones. This is not the case, as Dr. Don's results and Mr. Murphy's assays show.

3.—The gold came from magmatic sources. Practically all the available evidence is in support of this theory.

That the veins were formed from solutions passing through cracks and fissures in the dyke rocks is certain from the replacement of the wall-rock adjoining the veins and the comb structure exhibited by many reefs.

The nature of the minerals formed by the intense metasomatic alteration of the dyke wall rocks by the vein-solutions shows that the latter were considerably heated ascending solutions rich in alkaline carbonates, and containing also small quantities of iron, sulphur, arsenic, antimony, &c. That these solutions were the vehicles for the introduction of the gold is undoubted. Gold is known to be soluble in alkaline sulphides, and such were present in the vein-waters.

The constant association of the auriferous veins with dyke rocks of dioritic and gabbroidal composition is more than fortuitous, and admits of only one conclusion—namely, that they are of congeneric origin. The reefs occur within, intersecting and directly associated with the dykes, and nowhere do the latter cut the former.

The magma from which the dykes originated was a hydrous one, as is proved by the abundant hornblende, biotite, and apatite in these rocks. Furthermore, the regional magmatic and propylitic alterations were caused by silicious and alkaline carbonate waters of magmatic origin, and it seems reasonable that the alkaline carbonate vein-waters had a similar genesis.

4.—Paragenesis of the Vein-Minerals.

The opaque minerals present in the veins are pyrite, arsenopyrite, bournonite, tetrahedrite, sphalerite, galena, chalcopyrite, stibnite, jamesonite, and gold.

The gangue minerals consist of quartz, calcite, dolomite, ankerite, albite, and occasionally sericite, and in one case chrome-bearing mica.

The percentage of sulphides in the reefs averages about 1 %.

The gold is generally free, and in most cases it is fairly coarse. In many mines the gold is intimately admixed with bournonite. Thin sections of the ore from the A 1 mine show the relationship of these two minerals very well. In one specimen from the 850-ft. level the bulk of the gold is disseminated through the bournonite, and in places encrusts it. In other parts of the section veinlets of bournonite traverse the gold. Idiomorphic quartz crystals and some sphalerite are included in the bournonite. The sphalerite is coated and replaced by bournonite and chalcopyrite, and the latter mineral encrusts the bournonite.

Specimen No. J11, rich ore, No. 9 intermediate level, A 1 mine.—The gold is disseminated through the bournonite, and both minerals vein and replace sphalerite. Practically the whole of the gold is in direct association with the bournonite. Quartz and pyrite and sphalerite are included in this latter mineral, and some of it replaces finely-divided pyrite. That both the gold and the bournonite are essentially contemporaneous is undoubted.

In many mines the gold is more intimately associated with arsenopyrite. This is the case in the Morning Star and Rose of Denmark mines and in most of the narrow dykes—*e.g.*, Dempsey's, Star of Erin, Little Comet, Georgia, and Long Tunnel, &c.

In specimen No. J5, from the 400-ft. level, Morning Star mine, the gold occurs coating, veining, and replacing the arsenopyrite, and no gold is seen away from this mineral.

In another specimen from the No. 2 level below main adit level, Rose of Denmark mine, the gold occurs encrusting and veining the arsenopyrite, and both minerals are later than the quartz.

In specimen No. J8, No. 9 intermediate level, A 1 mine, the gold occurs intimately associated with arsenopyrite along an irregular lamination in the quartz; portion of the gold veins and replaces the arsenopyrite.

In a thin section of auriferous quartz from the 220-ft. level, Little Comet mine, the gold in part encrusts arsenopyrite, and both minerals vein the ankerite and quartz.

Pyrite is a common vein-mineral. It is almost invariably auriferous, but examples of visible gold in direct association with it are unusual, except near the surface, where the gold has been released by the breakdown of the pyrite—*e.g.*, All Nations and Champion mines.

In specimen No. J2, 850-ft. level, A 1 mine, the bulk of the gold occurs encrusting finely-divided pyrite of replacement origin.

In specimen J42, dark-coloured auriferous quartz, No. 2 level below main adit level, New Loch Fyne mine, some of the gold is deposited on grains and strings of pyrite of replacement origin.

At least two generations of pyrite are recognizable in the quartz-veins—

(1) Dusty and granular pyrite, replacing with quartz brecciated fragments of the wall-rock. This type antedates all the other vein sulphides.

(2) Granular and euhedral pyrite, apparently introduced with the vein-solutions, and usually of later origin than the bournonite, arsenopyrite, and gold.

A third generation of pyrite, occurring near the base of the vadose zone in some mines—*e.g.*, Little Comet, New Lauraville, and All Nations—is occasionally rich in gold. Such pyrite is of secondary origin.

Sphalerite is present in many reefs, usually in small quantities. It is always later than the quartz and carbonates of the veins, but, with the exception of pyrite, it precedes the other sulphides and metals. As mentioned above, in specimens from the A 1 mine the sphalerite is included in bournonite, and in places is coated and veined by this mineral, and also gold. In one section a grain of pyrite is included in the sphalerite. In another specimen from above a fault between the No. 5 and No. 6 levels in the Rose of Denmark mine, small euhedral crystals of sphalerite are partly encrusted by gold.

Galena does not appear to be a common constituent of the veins in the dykes, but is often present in considerable amounts in the reefs outside the dyke belt, as at Store Point. Its relations with the other vein-minerals are generally obscure. At the Rose of Denmark mine it is of earlier generation than the gold, as the latter mineral encrusts and veins it.

Tetrahedrite is present in some mines—*e.g.*, Hunt's, Dempsey's, Rose of Denmark, New Loch Fyne, and Little Comet. It is distinguished from bournonite by its greyer colour, its lower specific gravity, its greater tendency to tarnish, and by the fact that it contains little or no lead. In specimens from the Rose of Denmark and Little Comet mines the gold was seen to be intimately admixed with tetrahedrite, and both were essentially contemporaneous.

Chalcopyrite is present in small quantities in most reefs. In one specimen from No. 8 level, A 1 mine, it is of later generation than the sphalerite and bournonite. At the Rose of Denmark mine it veins and replaces the tetrahedrite.

Carbonates (calcite, dolomite, and ankerite) are present in practically all reefs, whether in dykes or in sedimentary rocks. Normally, they line the vein-walls. Their subsequent origin to the quartz is well exemplified in many mines. Specimens from the Morning Star, A1, and Rose of Denmark dykes show ankerite and dolomite encrusting idiomorphic quartz crystals. In other examples—*e.g.*, Evening Star, Wood's Point, Little Comet, and Cohen's reefs—the quartz and carbonates are interlaminated, and are essentially contemporaneous.

The composition of the vein-carbonates is generally ankeritic or dolomitic, but calcite is sometimes present. An analysis of a delicate pink-coloured bladed vein-carbonate from the 220-ft. level of the Little Comet mine, Wood's Point, gave the following results. Appended for comparison are analyses of vein-carbonates form Bendigo and Kalgoorlie.

—	1	2	3	4
	%	%	%	%
SiO_2	—	—	1.33	small
Fe_2O_3	tr.	—	0.73	1.27
FeO	6.49	3.87	5.86	8.63
MgO	18.20	19.46	16.96	15.86
CaO	29.04	29.70	29.79	28.88
MnO	0.47	0.67	tr.	—
CO_2	45.97	46.40	45.65	45.42
Totals ..	100.17	100.10	100.32	100.06

1.—Manganiferous ankerite, vein in Little Comet dyke, near rich gold, 220-ft. level. Analyst, N. R. Junner.

2.—Vein in serpentine, Hannan's Lake mine, Kalgoorlie (No. 42. p. 126).

3.—Carbonate crystals from vugs in a gold-bearing spur, stopes below 325-ft. level, Little 180 reef. Lansell's Little 180 mine, Bendigo, (No. 44. p. 20).

4.—Carbonate from vug in Nell Gwynne reef, North Bendigo mine, Bendigo. Analyst, J. C. Watson (No. 44, p. 20).

The Little Comet specimen has the approximate formula 10 $CaCO_3$, 9 $MgCO_3$, 2 (FeMn) CO_3, which closely resembles certain so-called "Unusual Dolomites" * from the Simplon tunnel, which have the following formulæ, viz. :—

1.—3 $CaCO_3$. 2 $MgCO_3$. $FeCO_3$.
2.—4 $CaCO_3$. 3 $MgCO_3$. $(FeMn)CO_3$.

As will be seen in the sequel, the vein-carbonates in the Walhalla–Wood's Point belt in some cases appear to have caused deposition of the gold.

Albite is not an uncommon vein-mineral. It is usually pellucid and little altered. In one specimen from No. 2 level below main adit level, Rose of Denmark mine, the albite is included in carbonates, and is clearly of earlier generation. In another section, No. J10, of vein-quartz from No. 6 level in the same mine, the albite precedes the carbonates.

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* Neues Jahrb. Min. Geol., 1913.

In specimen J18, from No. 4 adit level, Working Miners' mine, Kevington, the albite and quartz are contemporaneous, and earlier than the carbonates.

Albite has also been noticed in quartz-veins in the Little Comet, New Loch Fyne, and Hunt's mines.

Viewed broadly, the order of deposition of the vein-minerals in this belt is as follows:—

Primary Zone	Quartz, albite, pyrite, and carbonates.
	Carbonates.
	Sphalerite.
	Galena and arsenopyrite.
	Arsenopyrite, bournonite, tetrahedrite, stibnite, and gold.
	Chalcopyrite and pyrite.
Vadose Zone	Arsenopyrite, pyrite, and calcite.
	Gold.

5.—Factors Causing Localization of the Gold.

A.—FAVOURABLE STRATIGRAPHICAL ZONES.

The "favourable stratigraphical zone" theory originated with Mr. Dunn, who claimed that at Bendigo there were present three stratigraphical zones in which the auriferous values were markedly different (No. 11)—

(1) The lowest zone of strata, which are exceptionally favourable to the occurrence of gold.

(2) A higher less auriferous zone.

(3) A still higher barren zone.

The late Dr. Hall (No. 19, p. 77), after a study of the Castlemaine goldfield, stated that "It appears that the auriferous strata of our Lower Silurian (Ordovician) rocks begins above the base of the apparently thick *Tetragraptus fruticosus* zone, and ranges at any rate as high as Phyllograptus does, but probably no higher."

Mr. T. S. Hart's observations at Daylesford (No. 22) led him to similar conclusions to those of Dr. Hall—namely, that the more important reefs are associated with Bendigonian and Lower

Castlemaine beds, and that the non-productive and barren zones are in beds on a higher horizon.

Mr. Dunn (No. 13, pp. 41, 42) has extended his "favourable zone" theory to the quartz reefs in the belt of country between Wood's Point and Jamieson. He says:—"Where the reefs are in a productive zone and in contact with dykes they are auriferous; but if the reefs occur in contact with dykes in barren zones of country rock there is no gold."

Notwithstanding the views of these able geologists, the difficulties with which the "favourable zone" theory has to contend are great. Rich auriferous reefs have been worked in rocks of pre-Cambrian age, in all zones of the Lower Ordovician except the Darriwill (which, apparently, is of very limited occurrence), in the Upper Ordovician, and in both Melbournian and Yeringian divisions of the Silurian. At Bendigo, according to Dr. Stillwell (No. 44, p. 54), highly profitable reefs occur outside the No. 1 area of Dunn (*vide supra*), and many reefs within this area have been unproductive.

Dr. Hall's contention that no gold occurs in rocks of Lancefieldian age has since been disproved.

In the belt considered in this paper the bulk of the gold has come from reefs within dykes, and it is difficult to see how the surrounding strata could have influenced the values. Further, more, rich auriferous reefs occur in beds having a wide stratigraphical range, at least from the base to the top of the Silurian. It is admitted that the best paying reefs occur within the Walhalla beds, but this is regarded as being an outcome of the geosynclinal structure of the belt.

B.—STRUCTURAL FEATURES—FOLDING AND FAULTING.

In many Victorian goldfields a close connection is evident between structural features—domed fractured anticlines, geosynclines, and faulting—and the broad localization of the gold.

At Bendigo, Mr. H. S. Whitelaw (No. 53, p. 47) claimed that there was a direct association of the gold shoots with the faults, and Dr. Stillwell's (No. 44, p. 56) and Mr. Pabst's (No. 38) observations strongly support this view.

At Castlemaine the best-paying reefs occurred near the crest and on the eastern limb of a domed geanticline.

At Ballarat East there was a close connection between the rich shoots and pockets of gold and the cross-courses. Numerous other instances of a similar nature could be quoted from other Victorian fields.

At least 90 % of the gold won from the Walhalla and Wood's Point belt has come from the central geosynclinal area. A glance at the map will show the marked localization of the dykes and chief mines in this central area. A moderate amount of gold has been won from the Royal Standard–Store Point line of reefs. However, these reefs occur in a well-defined structural zone of highly crumpled and faulted slates and phyllites.

C.—PETROLOGICAL CHARACTERS OF THE DYKES.

A detailed petrological examination of the dykes of this belt has brought to light the following interesting facts :—

(1) The richest auriferous reefs occur within or associated with rocks of dioritic or gabbroidal composition.

(2) More acid types — quartz and feldspar porphyries and granophyres—although fairly common, have yielded negligible quantities of gold.

(3) Small quantities of copper, nickel, and platinum and traces of gold and silver occur in all the more basic types—hornblende, peridotites, &c.—but no case is known of a payable auriferous quartz-vein being worked in them.

The most favourable rock for gold is one having a composition allied to that of the A 1, New Loch Fyne, and Morning Star types —*i.e.*, a diorite, porphyrite, or lamprophyre (camptonite) originally rich in brown hornblende.

Good gold was won from the Tubal Cain dyke—a rock of basaltic composition rich in augite and deficient in hornblende, but it is the only case known from this belt of non-hornblendic dyke rocks carrying auriferous quartz-veins.

Three dyke expansions which, although intersected by promising quartz reefs, have yielded little or no gold, are the Alabama, near

Matlock; dyke at "r" in "Jericho" on map; and Raymond's, near Gaffney's Creek. Microscopical examination of these rocks shows that they consist mainly of phenocrysts of feldspar—predominantly orthoclase, quartz, and altered hornblende in beautiful granophyric and microspherulitic intergrowths of quartz and feldspar.

D.—PROPYLITIZATION AND VEIN-ALTERATION.

Professor Gregory, in his description of the rocks near Wood's Point and Gaffney's Creek, states:—"It is probable that the gold will be found most in the diorites where propylitization has been apparently most thoroughly effected" (No. 17, p. 34).

The writer's study of these relations has convinced him that—

(1) The propylitization is independent of and earlier than the vein-alteration.

(2) The gold was introduced with the vein-waters and not with the solutions causing propylitization.

An investigation was undertaken to discover whether the gold values anywhere varied with the intensity of the hydrothermal alteration, but no specific instance of a direct relation between the two factors was discovered.

E.—VARIATION OF TEMPERATURE AND PRESSURE.

The nature of the propylitic and vein-alteration undergone by the dyke rocks strongly suggests that the now exposed portions of them were formed under conditions of moderate temperature and pressure.

Estimates of the amount of vertical denudation since the folding give 6000 ft. as a minimum figure, and, as the reefs are believed to have been formed at the same period as the folding, the above figure gives us an approximation to the depth below the then surface of the now exposed parts of the reefs.

Rapid variation of temperature and pressure would not be likely at these depths, and, even so, it would be insufficient to account for the extremely capricious nature of the gold-values in some mines.

The Long Tunnel mine, which reached a vertical depth of 3675 ft., is the only deep mine in this belt. Averaging the values throughout, a slight decrease is noted in depth. Such is probably due to variation of temperature and pressure.

F.—NATURE OF THE WALL-ROCK.

It has been demonstrated conclusively by members of the Geological Survey and others at Ballarat, Daylesford, Bendigo, and elsewhere in Victoria that certain bands of carbonaceous slate and pyritic seams have frequently a favourable effect on the auriferous values of the reefs intersecting or adjoining them.

In the belt considered in this paper local examples of the same nature are not uncommon. For instance, at the Long Tunnel mine, Walhalla, the presence of a graphitic or carbonaceous slate on the wall of the reef was considered a very good indicator of the proximity of gold. Mr. Baragwanath, who made extensive surveys of this mine, gives sections indicating that the proved main shoot of gold between the 1300-ft. and 3000-ft. levels follows very closely the theoretical intersection of the reef with a narrow band of strata (No. 3).

In the Morning Star mine, at the 500-ft. level, a local enrichment occurred on the eastern wall, where the quartz floor passed out of the dyke and cut a band of black slate.

At the A 1 mine, between the 850-ft. and 1000-ft. levels, the reefs normally intersect two dykes and much hard sandstone and quartzite, and sometimes near the lode walls they cut across bands of black slate. Although auriferous throughout, the reefs were richer within the green-mottled, highly-carbonated, mica–hornblende–lamprophyre dyke—the "kindly country rock" of the miners—and in the slates, than within the quartzite.

Reefs occupying fault-planes which intersect and displace dykes are common in the northern portion of the belt. Considerably enriched values at and close to the intersections of the reefs and dykes are the rule in such cases. However, none of these have been worked in the zone of primary values, and it can be demonstrated in many cases that the concentration of the gold at these points is due to secondary enrichment.

G.—REPLACEMENT.

Throughout this belt the richest quartz reefs in the zone of primary values, whether within dykes or in Silurian sediments, are of the laminated type. Microscopic study of thin sections of these reefs by the writer has convinced him that they are largely of replacement origin, as Dr. Stillwell (No. 44, p. 34) has ably demonstrated for the laminated quartz reefs at Bendigo.

An examination of the auriferous quartz from the Long Tunnel, Fulton's, Harbinger, and Star of the West mines, all of which occur within sedimentary rocks, shows a marked aggregation of the gold—which is usually very finely divided—along the laminæ, the carbon, arsenopyrite, and pyrite of which appear to be the main precipitating agencies for the gold. Much of the quartz is of replacement origin, and the laminations are believed to represent unreplaced flakes and films of the wall-rock, impregnated and encrusted with dusty and minutely-crystallized pyrite and arsenopyrite.

In reefs within dykes the quartz is sometimes laminated. Often the central portion of the reef is composed of white quartz slightly laminated, while the marginal variety is well laminated and frequently dark in colour, due to finely-divided sulphides.

Ankerite or ferriferous dolomite normally lines the vein-wall.

The most obvious characteristic of the gold occurrence in the reefs in dykes is its marked localization in the quartz adjoining the vein-walls. Microscopical examination has shown that this latter quartz has originated by replacement of the wall-rock. Partially replaced fragments and undigested residues of dyke material are common in the quartz. Finely-divided pyrite and some arsenopyrite are extensively developed in the process of replacement. That these sulphides have played an important part in precipitating the primary gold is evident from the way in which the gold encrusts and replaces them in specimens from the Morning Star, New Loch Fyne, A 1, Rose of Denmark, and Little Comet mines (*vide supra*, p. 207). In other cases, galena, sphalerite, vein-carbonates, and rock residues have apparently caused the precipitation of the gold. The marked concentration of the gold in the marginal quartz of replacement origin is believed to be due to the greater concentration of the above-mentioned precipitants in these parts of the veins.

The dykes themselves are apparently capable of precipitating the gold from the vein-solutions, for certain specimens from the 850-ft. level, A 1 mine, show facings of gold with little or no quartz or sulphides on joint planes near a rich floor in the mottled mica–hornblende–lamprophyre referred to above.

Examples of gold deposited on carbonates (ankerite, dolomite, and calcite) are not common. The writer has seen specimens of dolomite from the A 1 mine with specks of gold adhering to them; of calcite from the Georgia and Unknown mines with gold included in and intermingled with it; and of ankerite from the 220-ft. level, Little Comet mine, Wood's Point (*vide* microphotograph No. 21), encrusted and veined with leaf gold. However, the gold in this last-named specimen and in the ones from the Georgia and Unknown mines is possibly of secondary origin.

H.—SECONDARY ENRICHMENT.

Examples of the concentrating effects of secondary enrichment on the gold by gravitation and solution are extremely common throughout this belt. Perhaps the best case of great mechanical concentration at and near the surface is the Royal Standard mine which yielded considerably more than £50,000 worth of gold from quartz averaging about 2 oz. to the ton from the surface to a depth of 70 ft. Very little gold has been unearthed from below this level.

Another illustration is the Specimen mine, near Ten-Mile, the quartz from which averaged nearly 51 oz. to the ton from the surface to a depth of 32 ft., and became unpayable below 100 ft.

Examples of rich pockets and shoots of gold near the base of the zone of surface decomposition, and particularly at points where the descent of auriferous solutions has been checked, are plentiful. The types of obstruction which appear to have been particularly favourable to the localization of the gold are as follows :—

(1) Ledges formed by small rolls in the dykes and reefs and by small faults intersecting them—*e.g.*, Georgia and Knowle's dyke, &c.

(2) Flat or rising veins proceeding from the dykes into the strata—*e.g.*, Morning Star dyke. These veins obstruct the descent of auriferous waters along the dyke walls.

(3) The intersections of steeply-dipping veins with flat or rising ones—*e.g.*, Little Comet and Leviathan mines. The Morning Star dyke provides what is believed to be the best illustration of vadose shoots of gold. According to Mr. O. A. L. Whitelaw (No. 55, p. 16), " the Age of Progress reef was worked for a length of 1500 ft. along the western wall, and Cherry's reef for 1100 ft. on the eastern wall." These reefs were relatively poor in the centre of the dyke, but were extremely rich on the walls, as the following recorded returns for the years 1864 and 1865 show :—

27,933 tons of quartz yielded 94,075 oz. of gold.

Summary of the Factors Causing Deposition and Localization of the Gold.

1. Structural features are believed to be far more important than stratigraphical zones in causing the localization of the gold.

2. Physical features, such as variation of temperature and pressure, apparently have played an unimportant part in causing the deposition of the gold.

3. Payably auriferous reefs are found in or associated only with dykes of dioritic or gabbroidal composition.

4. The main deposition of primary gold in the reefs appears to have been due to the chemical precipitation of the gold in the ascending auriferous solutions by the previously-formed sulphide minerals—pyrite, arsenopyrite, sphalerite, and galena—and by carbonaceous and other rock residues, and occasionally by the vein-carbonates.

5. Secondary processes—denudation, gravity, solution, and re-deposition—have re-concentrated the primary gold-forming important shoots and pockets of gold within the vadose zone.

6.—THE RELATION OF VICTORIAN AURIFEROUS REEFS TO IGNEOUS ROCKS.

Auriferous quartz-veins occur within or directly associated with igneous rocks of various types in Victoria. They occur in granodiorite at Maldon, Dargo, Mount Wills, Hillsborough, Warburton. and elsewhere.

Auriferous pegmatites are known from Huon's Lane (in North-Eastern Victoria), Nuggety Reef (Maldon), and from Lintons.

Gold-bearing reefs occur in sericitized and silicified quartz–feldspar–porphyry dykes at Diamond Creek, Foster, Blakeville, Maldon, Stawell, Kinglake, Queenstown, Warburton, &c.; and in other localities, as at Sebastopol, near Ballarat, and at Maryborough, they are closely associated with similar dykes.

Few of the mines occurring within the above-mentioned rocks have yielded large quantities of gold. They are of scientific interest, but rarely of economic importance.

Whenever there is a direct connection between dykes and auriferous quartz-veins, as is the case on many of our goldfields, it is generally with rocks of intermediate to basic composition, In the Walhalla-Wood's Point belt, as previously mentioned, all the best reefs are associated with rocks of dioritic or gabbroidal composition, and the reefs connected with more acid and more basic types have yielded little gold.

Another very important and interesting belt where similar relations exist is that extending through Creswick, Clunes, Talbot, Maryborough, Dunolly, and Wedderburn—the fabulously rich alluvial belt of our colony.

Closely associated with the reefs in this zone are two distinct types of dykes—

(1) Acid types—quartz and feldspar porphyries.

(2) Intermediate to basic types—diorite and gabbro porphyrites and lamprophyres.

The reefs related to the first class of dykes have yielded little gold. The second class occur, as in the Wood's Point area, in two ways, viz.:—

(*a*) As lenticular expansions or pipes—*e.g.*, Rheola, Talbot, Spring Hill, and Central Leads (near Smeaton), and at Tarilta and Metcalfe, some miles to the east of this belt.

(*b*) As narrow dykes at Wedderburn, Rheola, Moliagul, Dunolly, Maryborough, and Amherst.

The rocks of the dyke bulges are normally dioritic in composition, and frequently show green chloritized phenocrysts of hornblende and pink feldspar in hand specimen. In thin section they are seen to be closely allied to the Morning Star and New Loch Fyne types described above. They are characterized by much-altered—chloritized, carbonated, and epidotized—brown hornblende, chloritized and sericitized plagioclase, and clear quartz in a ground-mass which has been re-crystallized generally in the form of a micrographic intergrowth of quartz and feldspar. The characteristic minerals of the propylitic *facies*—namely, pennine, epidote, massive carbonate, pyrrhotite, and pyrite—are all present. In most cases these rocks are closely associated in the field with quartz-feldspar-porphyry dykes, and it is probable that they are differentiation products of a common magma.

Although quartz reefs are uncommon within these dyke expansions, they are numerous in the contact rocks, and rich alluvial gold has been won from the vicinity of practically all of them.

The gullies heading towards the Talbot dyke expansion were particularly rich near the dyke, and the same is true at Tarilta.

According to Professor J. W. Gregory (No. 16, p. 10), "The bed-rock at the Spring Hill and Central Leads is penetrated by a broad dyke which is closely related to the rock of the dyke in the New Loch Fyne mine at Matlock, and it is not surprising that it has caused the deposition of the gold in the adjacent slates, and that the old river gravel beside it should be rich in gold."

At Rheola outcrops of hornblende diabase and diorite porphyrite, which have been altered along their contact by the granodiorite, are not uncommon. Numerous lamprophyre dykes are also present. The alluvial in the vicinity of these rocks was notoriously rich in large nuggets.

The narrow dykes are in the main much altered—carbonated, chloritized, and sericitized—hornblende and biotite lamprophyres—camptonite and spessartite. Fairly rich auriferous reefs occur within or adjacent to such dykes at Maryborough, Dunolly, Landsborough, Rheola, and Wedderburn.

Other areas in Victoria where gold-bearing reefs are known to be intimately associated with dioritic and gabbroidal rocks are Queenstown (near Melbourne), Granite Flat, and Dargo. In many other places in Victoria the nature of the dykes associated with the auriferous quartz reefs has not been investigated. Igneous intrusions of a more basic character than the above-mentioned are rarely if ever connected with auriferous reefs in Victoria.

Hence it is concluded that the favourable type of igneous intrusion for gold reefs in this State is one of dioritic or gabbroidal composition. Current belief connects our main goldfields with granodiorite intrusions. Viewed broadly, this is true, but it is generally with the intermediate and basic differentiates from the same magma from which the granodiorite has been derived that the most intimate connection is apparent.

7.—Fineness of the Reef Gold.

The gold saved by amalgamation varies in fineness from about 800 (as in the case of the Lady Vera, near Fulton's Creek, and the Morning Star) to 960 or 970 (as in the Franklin, Eldorado, and A 1 mines).

Apparently the nature of the vein-sulphides has influenced the fineness of the gold. Where stibnite is the predominant sulphide —*e.g.*, Leviathan and Royal Standard mines in this belt, and at Alexandra and elsewhere in Victoria—the gold is invariably of good quality.

Where the vein-sulphides are chiefly sulpharsenides and sulphantimonides — *e.g.*, bournonite, tetrahedrite, jamesonite, and arsenopyrite—the gold is usually of good quality, as is the case in the A1, Eldorado, Wallaby, All Nations, Sir John Franklin, Dempsey's, Georgia, and Little Comet mines. The Long Tunnel gold, however, was of relatively poor quality (820–860), although associated with arsenopyrite, bournonite, and pyrite. Where galena and sphalerite predominate in the veins the gold is rarely of good quality—*e.g.*, Rose of Denmark (845–880), and the New Loch Fyne (830–870).

In general, the average fineness of the gold from reefs within dykes is not less than that of the gold from reefs in the sedimentary rocks.

Descending vadose waters apparently have refined the gold, as almost invariably the gold from shallow workings of less than 300 ft. is of good quality—*e.g.*, Unknown, Eldorado, Royal Standard, Little Comet, Georgia, &c. In the Rose of Denmark mine the gold from the primary zone was of lesser fineness than that from near the surface. Dr. Don's analyses of Victorian vein-gold indicate that on the whole the average fineness of the gold in the vadose region is appreciably greater than that from the primary zone in the same district (No. 10, pp. 607, 608).

PART III.—SECONDARY ENRICHMENT IN THE MINES BETWEEN WOOD'S POINT AND JAMIESON.

1.—Introductory Remarks.

On glancing through the geological and mining literature of Victoria, one is struck by the paucity of references to undoubted cases of secondary enrichment in our auriferous ores. On looking for a reason for this, three possibilities are suggested—

1. The scientific investigation of the problem has been neglected. Certainly, no detailed study of the question has been made on any of our mining fields, and the few scattered references to the subject in the literature are, on the whole, brief and inconclusive. Furthermore, the upper oxidized zones of most of our mines were worked out in the early days of gold mining before the *rôle* of secondary enrichment in re-concentrating the gold was understood, and consequently there are very few facts relevant to the subject preserved in the literature.

2. Difficulty of recognition.

The gold won from the more important mining fields of Victoria is noted for its free-milling character. The chemically unstable sulphides of copper, lead, iron, and zinc, which afford elsewhere excellent criteria for determining secondary enrichment, are associated normally with the gold in small quantities, but their occurrence in large amounts is exceptional. Complex refractory auriferous ores occur at Bethanga and Cassilis, in the north-east of Victoria, but they are of no great economic importance.

3. The effects of secondary enrichment on our auriferous quartz-veins may have been so small as to have been of no economic importance. This, the writer believes, is a fairly widely accepted view.

The purport of this section of the paper is to show that many mines of this belt have suffered important enrichments by mechanical concentration and chemical migration of the gold contained in the reefs.

2.—Secondary Enrichment.

A.—DEFINITION.

To avoid misconception, it would be well to define precisely what we mean by secondary enrichment. This term is used here, firstly, for the enrichment at and close to the surface, by the mechanical concentration of the gold derived by denudation from the former upward extension of the auriferous quartz-veins; secondly, for the enrichment in the vadose zone by the breaking down of the auriferous sulphides by descending surface waters, which carry away the base metals and their salts in solution, leaving the gold in situ; and thirdly, for the enrichment in the vicinity of the base of the vadose zone by the solution of the gold from and near the surface by descending waters and its subsequent re-deposition in more concentrated form at a lower depth, which, in most mines in this belt, is between 150 ft. and 300 ft.

B.—PREVIOUS LITERATURE.

Mr. H. A. Thompson (No. 49, p. 248) suggested that the decrease in gold-values as mining became deeper was due to the surface alteration of the dykes.

Mr. R. A. F. Murray (No. 35, p. 123), who was a loyal supporter of the permanence in depth of the auriferous values in these veins, recognized that secondary enrichment had played some part in localizing the gold. He says, speaking generally of Victoria :—

"On the average, richer quartz has been obtained from the surface portions of the reefs generally than has been met with in the deeper levels."

And again—

"We must consider also the reactions produced by meteoric waters proceeding from the surface downwards, and this process is partly one of decomposition and partly one of concentration."

Mr. O. A. L. Whitelaw (No. 55, p. 14), dealing with the Wood's Point area, states that

"It is a commonly-accepted belief among miners in the district that decomposition has had considerable influence upon the occurrence of the gold. The greasy decomposition product, 'mutton fat,' is regarded as one of the best indications of the proximity of gold."

C.—THE MECHANICS OF SECONDARY ENRICHMENT.

Nowhere in this belt is there found any evidence of marine conditions later than the folding of the Silurian sediments—*i.e.*, since Devonian times.

No exact figure of the amount of vertical denudation since this period of folding and intrusion of the dykes and auriferous quartz-veins can be arrived at, but estimates from vertical sections constructed from dips give 6000 ft. as a minimum figure.

Postulating the extension of the auriferous quartz-veins to the surface at the time of their formation, which seems reasonable, what, then, has become of the gold released from these reefs? Some of it has been carried away by past and present-day streams. The sub-basaltic gravels at Moondarra, near Walhalla, and on the Thomson–Aberfeldy divide have furnished little gold, and, although the alluvial terrace deposits and gravel beds of the present-day streams have locally yielded rich results, on the whole they have been much poorer than similar deposits on other Victorian goldfields.

The factors that have determined the ultimate fate of the gold derived from the former upward extensions of these reefs are as follows, viz. :—

(1) The relative rates of denudation and solution of the gold.

(2) The degree of permeability of the dykes, sediments, and quartz-veins to surface descending waters.

(3) The chemical nature of these waters.

(4) The amounts of sulphides present in the quartz-veins and the dykes and the nature of the products derived by their decomposition.

(1) If denudation progresses faster than the solution of the gold by surface descending waters, then a large part of the gold will be washed away into the gullies and streams before it has had time to dissolve. In the ideal case we should expect fairly rich alluvial deposits and practically no change in the tenor of the quartz from the surface down to the zone of primary sulphides. If, on the other hand, the chemical leaching of the gold proceeds at a more rapid pace than the denudation, we should have in the ideal case little or no alluvial gold, a barren or poor surface zone,

and a considerable enrichment near the base of the vadose zone. As the degradation of the rocks proceeds, the gold in this enriched zone will in its turn be dissolved and re-deposited at a lower level. Consequently, in the extreme case, we should get the whole of the gold from the former upward extensions of the reefs concentrated near the water-level, with poor values above and the unenriched ore below. No example of this type is known from this belt.

If denudation and solution keep pace one with another, the outcome should be payable alluvial, payable or slightly enriched surface ore, and an enrichment near the bottom of the vadose zone. This state of affairs is well illustrated in many of the mines in this belt—*e.g.*, All Nations, Morning Star, Hunt's, New Loch Fyne, &c.

(2) The degree of permeability of the dykes, &c.—That the dykes and quartz-veins have provided the easiest channels for descending waters is proved by the much greater depth of decomposition in them than in the surrounding sediments. In many dykes, more especially the dyke expansions, the waters appear to have proceeded by certain localized channels, and did not permeate the whole of the dykes. For example, in the Morning Star, New Loch Fyne, Luck's All dykes, &c., numerous patches of hard, undecomposed rock outcrop at the surface, although in all these cases, at depths between 200 ft. and 300 ft., the dykes are greatly decomposed.

Frequently the walls of the dykes have provided the readiest conduits for the surface waters, and in many mines rich patches of gold, often free from quartz, occur along the dyke walls—*e.g.*, May Moon, Knowle's, Waverly, Georgia, Sutcliffe's (near Matlock), and Morning Star mines.

In certain other cases finely-divided gold and films of gold are found along bedding planes and fractures in the country-rock near the surface. One specimen of soft mudstone from near the A 1 mine shows finely-divided gold without quartz on a bedding plane, and in another specimen from the Champion mine, near Ten-Mile, similar gold, free from quartz, occurs on a bedding plane in association with limonitized pyrite cubes. A piece of Cohen's dyke, from the 150-ft. level in the Long Tunnel mine, in the Ballarat School of Mines collection, shows free gold without any quartz on a joint plane or fracture in the rock, and similar examples have been seen in the A 1 dyke, near the surface.

The downward descent of the auriferous waters may be checked by impervious barriers, such as faults, rolls in the reefs and dykes, cross-veins, and other structural features, and the bulk of the gold will be deposited in close association with these barriers. Such gold will, in general, be prevented from migrating downwards in solution, and will, in the course of time, reach the surface. As a case in point, the famous Royal Standard reef consisted of the dissected remnants of a bedded synclinal vein, the trough of the reef being about 70 ft. from the surface (No. 57, p. 20). The mode of occurrence of the gold and the wonderful richness of the reef strongly suggest that the structure acted as a barrier to descending auriferous waters.

(3) The chemical nature of the vadose waters.—Variations from time to time in the chemical nature and amounts of the vadose waters will naturally affect the amount of gold going into solution. If no solvent is present, then no gold will be dissolved, and consequently in time it will reach the surface by denudation.

Of the solvents for gold, it is believed that free chlorine derived from the attack of sulphuric acid on manganese dioxide in the presence of soluble chlorides has been most potent. Sulphuric acid is formed by the oxidation of iron pyrites, which is present in all the dykes and most quartz-veins. Hydrated oxide of manganese in small quantities is ubiquitous near the surface. Almost every piece of quartz from near the surface contains stains and veinlets of psilomelane. Nearly all the dykes contain small amounts of MnO—*e.g.*, Morning Star, 0.14 %; New Loch Fyne, 0.15 %; and one specimen of the A 1 dyke, 0.23 %. Furthermore, the vein carbonates—ankerite, &c.—are usually manganiferous. One specimen of ankerite from the Little Comet mine gave, on analysis, 0.47 % MnO. Soluble chlorides are present in nearly all vadose waters.

D.—ENRICHMENT BY MECHANICAL CONCENTRATION AT AND NEAR THE SURFACE.

The chief criterion used in determining this type of enrichment is the occurrence of very rich surface-values, decreasing fairly rapidly in depth.

Several mines in this belt were wonderfully rich right at the surface, but failed to maintain their reputation in depth. For example, gold was seen glittering on the surface outcrop of the Royal Standard mine by the discoverers when 100 ft. away from it. The first recorded crushing from this mine yielded 2934 oz. of gold from 300 tons of ore, equal to about 9¾ oz. per ton. The total recorded yields up to November, 1866, are about 13,718 oz. of gold from 7000 tons of quartz obtained from the surface to a depth of 70 ft.

The first recorded crushing from the Specimen mine, near Ten-Mile, gave 610 oz. 11 dwt. of gold from 12 tons of quartz, from depths 0–30 ft. At a depth of 100 ft. 133 tons of ore yielded 458 oz. of gold. A lower tunnel cut the reef, but apparently it was poor, as work was soon discontinued.

Dempsey's reef, Gaffney's Creek, was extremely rich near the surface. In 1861, 7 cwt. of quartz from near the surface gave 153 oz. of gold, and, from a depth of 23 ft., 8 tons of quartz yielded 370 oz., and 100 tons averaged 15 oz. per ton. At 80 ft. the average tenor of the quartz had fallen below 10 dwt.

In 1865 some patches of extremely rich ore were taken out of the Eldorado mine from the surface to a depth of 30 ft., as will be seen by the following figures:—

June, 1865.—5 tons of ore gave 90 oz. of gold, 0–30 ft.

Sept., 1865.—9 tons of ore gave 448 oz. 12 dwt. of gold, 0–30 ft.

Dec., 1865.—7 tons of ore gave 64 oz. 10 dwt. of gold, 0–30 ft.

From 1864 to 1895, inclusive, 4720 tons of ore from this mine yielded 5333 oz. 13 dwt. of gold from the surface to a depth of 200 ft.

In the New Loch Fyne mine 2 tons of ore from the surface produced 73 oz. of gold. At depths between 40 and 55 ft. 372 tons of quartz yielded 1791 oz. of gold in 1864. No ore from greater depths ever approached this richness.

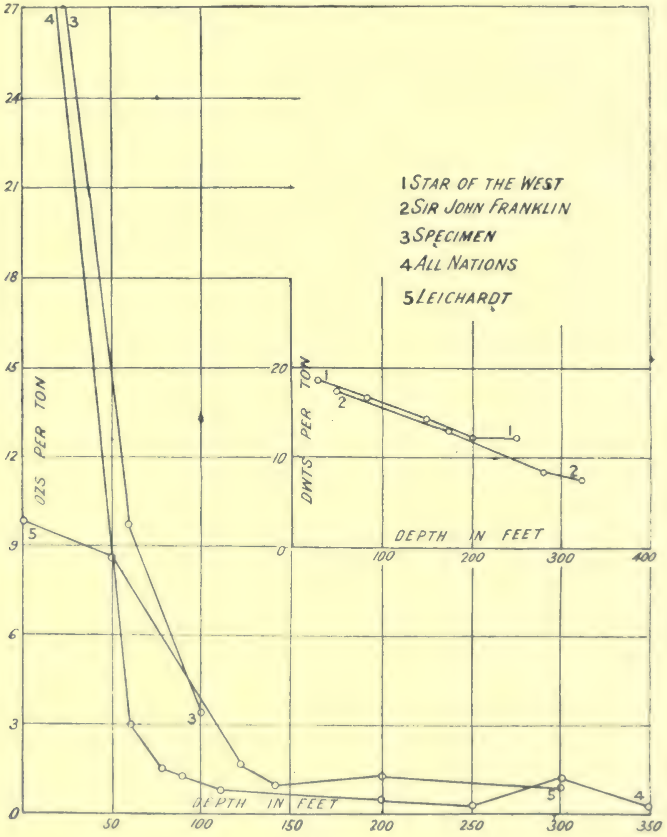

Fig. 5.

Graph.

Illustrating enrichment in auriferous values at and close to the surface.

The richness of the ore from the Leichhardt mine, Stander's Creek, near the surface, and its impoverishment with depth, are well illustrated by the following yields given by Mr. O. A. L. Whitelaw (No. 55, p. 29) :—

Depth	Ore Crushed.	Yields of Gold
	Tons.	oz. dwt
Surface	15	146 0
0–100 ft.	24	208 0
120 ft.	457	767 10
130–150 ft.	905	751 10
200 ft.	126	152 5
300 ft. (No. 3 level) ..	—	Av. 16

The first recorded crushing from the All Nations mine produced 165 oz. of gold from 1¾ tons of superficial ore. Some rich quartz was worked to a depth of 120 ft., but below this depth the total ore treated averaged less than 1 oz. per ton.

Again, in March and June, 1865, 295 tons of ore from depths of 0–30 ft. in Hunt's dyke yielded 633 oz. 17 dwt. of gold. At a depth of 80 ft. the tenor of the ore had fallen to less than 7 dwt.

The Never Mind, Johnson's, and Republic reefs, near Wood's Point, and the Shakespeare reef, near Gaffney's Creek, were all rich at and near the surface, but became unpayable at depths less than 200 ft. The first crushing from the Never Mind reef gave a return of 93½ oz. of gold from 10 tons of ore. According to Mr. D. B. Walker (No. 52, p. 12), £33,000 worth of gold was extracted from this reef between February, 1866, and November, 1867. Practically the whole of this gold came from an open cut 50 ft. deep. Below this depth the ore was not payable.

Other mines, such as the Sir John Franklin, Star of the West, and Sailor Bill's, show a progressive decrease in values from the surface downwards without any great marked surface enrichment (*vide* graph, fig. 5).

E.—ENRICHMENT IN THE LOWER PART OF THE VADOSE ZONE.

(*a*) *Criteria for Recognition.*—Numerous instances of enrichment in the auriferous values have been noted in the mines of this belt in the vicinity of the base of the zone of surface decomposition, which varies from a depth of 100 ft. or less to more than 350 ft. In most cases the enrichment can be proved to be due to the leaching of the gold from the upper portions of the veins by descending surface waters and its re-deposition in more concentrated form at lower levels.

The criteria used for determining this type of enrichment are as follows, viz. :—

(1) Statistical ; the occurrence of considerably enriched values near the base of the vadose zone.

(2) The mode of occurrence of the gold.

The gold from such enriched patches or zones in the lodes occurs in the following ways :—

(*a*) In mossy and fern-like growths ; in botryoidal form ; in crystals ; and as strings and veins filling cracks in friable quartz and country-rock. Such gold is normally associated with limonite and psilomelane, and sometimes with native copper, malachite, "mutton fat," and rarely with secondary sulphides.

(*b*) As nuggety and finely-divided gold, frequently free from quartz, on ledges and shoulders on the dyke or vein-walls ; at the intersection of steeply-dipping and more or less flat veins, and on relatively flat faults displacing the dyke or reef. The gold from these patches is sometimes coated with limonite and psilomelane or arsenopyrite, and at other times it is deposited on pyrite or arsenopyrite.

There can be no question of such gold being formed in any other way than from descending surface waters.

Fig. 6 illustrates graphically this enrichment in the lower portion of the zone of surface decomposition in certain mines.

The statistics from which the graphs were constructed were mostly culled from the quarterly reports of the mining surveyors and registrars of Victoria. The writer is quite aware that the recorded values of the ores are not in all cases true reflections of their average tenor. In certain mines some of the ore is hand-picked before crushing. In others a good deal of mullock is crushed with the quartz. Again, in many cases only the richest ore is mined. These factors, and the practice adopted by certain mine managers of keeping back some of the richer specimens from one crushing to equalize or boost others, all tend

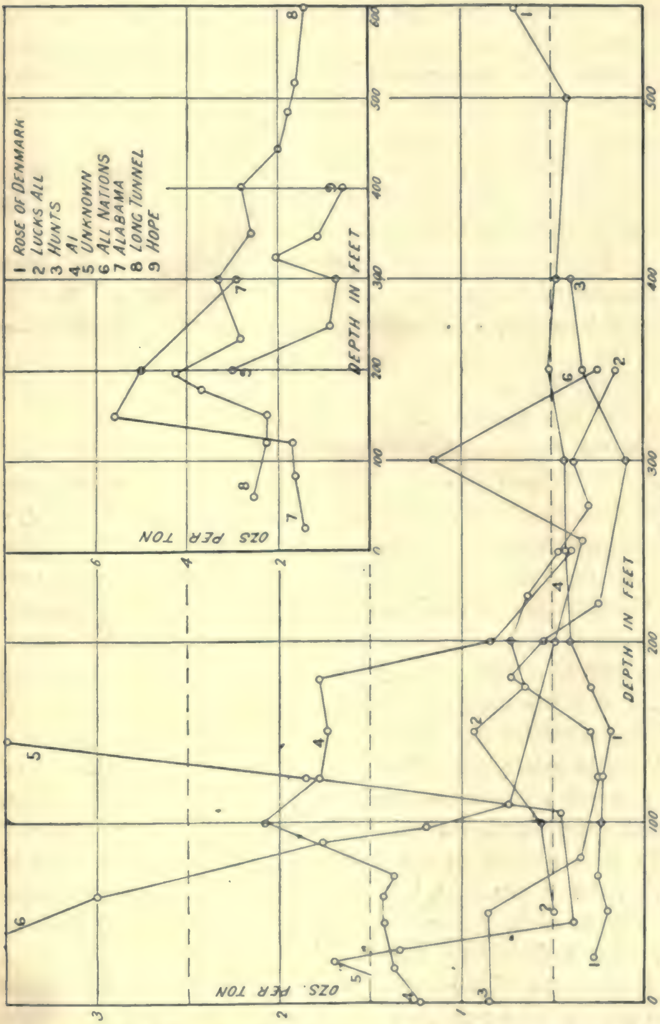

FIG. 6.
GRAPH.
Illustrating enrichment in auriferous values in the lower part of the vadose zone.

to place a false value on the ore mined. Nevertheless, the writer is of the opinion that the graphs give a fairly close approximation to the true values of the ore at the various depths indicated on them. Care has been taken to exclude as far as possible yields from small parcels of quartz, unless they are taken in conjunction with larger crushings from the same depth, also those returns where a wide range in depth is recorded, and others, again, where the depth is not given, or is uncertain.

The general conclusion to be drawn from the graph is that in certain mines—*e.g.*, Alabama (Ten-Mile), Luck's All, A 1, Long Tunnel, Hope (Morning Star), All Nations, and Unknown—enrichments, in some cases of considerable economic importance, have taken place at depths varying generally between 100 and 300 ft.

In the A 1 mine the enriched ore occurred at depths between 100 and 180 ft. from the surface; in the Long Tunnel, at about 200 ft.; in the Alabama, between 140 and 200 ft.; and in Hunt's, between 180 and 200 ft.

(*b*) *Detailed Account of Enrichment by Solution of the Gold and its Re-deposition at Lower Levels.*—Georgia mine, Railway Creek, near Enoch's Point.—Two dykes, about 10 ft. apart, dipping at high angles, 70°–80°, to the west are seen in this mine. They cut across the strata, which dips at angles varying between 40° and 50° to the east, at about 60° in dip and 40° along the strike. The western dyke, on which the bulk of the work has been done, averages 3 ft. in width, but enlarges locally to 10 ft., and pinches elsewhere to a few inches in width.

The characteristic flat veins of the narrow dykes are well exemplified in this mine. They average 2 to 3 in. in width. In places flat veins of coarse calcite and arsenical pyrites replace the usual quartz-ankerite veins. These flat veins or "floors" normally stop sharply at the dyke wall. They were worked in the early days of this field, between 1868 and 1881, and averaged about 3 dwt. of gold per ton. Thin veins of well-crystallized calcite, with a little iron and arsenical pyrites, occur in places between the walls of the dyke and the contiguous strata.

Small dip-slip faults displace the dyke a few inches, but rarely more than 6 in. At the intersection of the hanging wall of the dyke with these displacements, patches of coarse and of fine gold are frequently found (*vide* fig. 7).

Sometimes the dyke departs locally from its normal dip and rolls a few inches to the east, as in fig. 8. In such cases there is usually a ledge or shoulder of hard sandstone with the dyke wall.

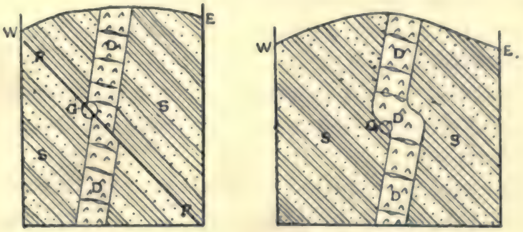

FIG. 7. FIG. 8.

SKETCH SECTIONS ACROSS THE GEORGIA DYKE, NEAR ENOCH'S POINT.
Showing localization of patches of gold—"G." "D" = lamprophyre dyke with flat quartz veins; "S" = Silurian slates and sandstones; "F" = fault.

These ledges are favoured places for the finding of patches of nuggety and fine secondary gold.

Coarsely crystalline gold in calcite is sometimes found in this mine where the flat veins of calcite and arsenopyrite intersect the hanging wall.

Thanks to the courtesy of Mr. F. Higgins, of Enoch's Point, the writer had excellent opportunities of studying the gold-occurrence in the Georgia mine and of examining numerous specimens taken from the above-mentioned patches on the ledges and fault-planes.

The gold from these places occurs in various forms—

(1) As nuggets practically free from quartz, and often coated with hydrated oxide of manganese and secondary arsenical pyrites —so-called "black gold." The largest nugget from this mine weighed about 36 oz., but several others up to 5 oz. in weight were unearthed. This nuggety gold is absent in the veins within the dyke, and is confined to the above-mentioned ledges and fault-planes. Two nuggets of black gold, free from quartz, in size and shape of a wooden match-box, were seen by the writer. They came from between the walls of the dyke and surrounding sediments, and their shape obviously had been determined by that of the walls.

(2) As loose fern and moss gold, which is often well crystallized and usually coated with pyrolusite and arsenical pyrites and red hydrated oxide of iron.

(3) As beautifully-crystallized gold — normally in form of octahedra or dodecahedra, and more rarely as cubes, sometimes bright, but more often coated by secondary arsenopyrite and psilomelane. Crystalline gold also occurs in calcite along the walls of veins within the dyke.

(4) As botryoidal gold deposited on earthy arsenopyrite.

(5) As finely-divided loose gold and coating arsenopyrite.

(6) As black gold.

Where the gold is associated with calcite it is almost invariably well crystallized, and frequently nuggety. One specimen of the gold from one of these ledges was in the form of a rosette of crystals, and was attached to a crystal of quartz.

Knowle's Dyke, Knowle's Creek, near Enoch's Point.—Knowle's dyke averages up to 6 ft. in thickness, and dips at a high angle to the east. It cuts across the strata, which dip here at about 40° to 50° to the east in strike as well as in dip, as in the Georgia dyke. The dyke carries the usual flat leaders of quartz, but in general they were found to be unpayable.

Some of the salient features of the gold-occurrence in this mine are as follows, viz. :—

(1) Practically all the gold came from the foot-wall of the dyke at its intersection with small bedded fault-planes, and from ledges where the dyke has altered its course locally, in exactly the same manner as in the Georgia mine.

(2) Several nuggets of fairly large size were unearthed from this mine. Mr. F. Higgins informs the writer that the first of any note, 25 oz. in weight, came from a depth of 150 ft., and that they were found to a depth of 300 ft. from the surface. The largest nugget found in this belt, 168 oz. gross and 150 oz. fine, came from this mine at a depth of 200 ft.

(3) None of this nuggety gold came from within the dyke; all of it came from the walls of the dyke.

(4) The nuggets were very free from quartz, and were often coated with secondary earthy arsenopyrite and psilomelane, and occasionally limonite.

(5) Quite a considerable amount of finely-divided crystalline and fern gold was found with the nuggets.

(6) Several nuggets, many of which were of the "black gold" type, were found in Knowle's Creek.

Waverly Dyke, Wood's Point.—Mr. Renwick, of Wood's Point, informed the writer that he obtained rich patches of coarsely-crystallized gold associated with little or no quartz on ledges near the surface on the hanging-wall of the dyke formed by small rolls.

Such ledges seem to be favoured places for the deposition of the gold, for Mr. O. A. L. Whitelaw (No. 57, p. 24) says, speaking of the Republic mine, near Wood's Point—

"The reef makes numerous rolls or pitches in a general northerly direction, and it is upon the 'shoulders' thus formed that the richer patches of gold have been found."

Again, according to Mr. R. A. F. Murray (No. 37, p. 43)—

"The quartz carrying the best gold at the Rose of Denmark mine seems to ride on slightly projecting ledges of the slate rock on the footwall."

May Moon Dyke, All Nations Mine, Matlock.—Rich patches of gold were unearthed by Messrs. Lawson Bros. from the wall of the May Moon dyke at a depth of between 150 ft. and 200 ft. One nugget, weighing more than 100 oz., was obtained by them at a depth of about 200 ft. between the dyke-wall and the country-rock; it was associated with much limonite, and practically free from quartz. According to Mr. O. A. L. Whitelaw (No. 55, p. 26), "The greater part of the gold is obtained not in the quartz leaders traversing the dyke, but in a brown clay or 'dig' which lies between the contact of the dyke and the sedimentary beds. The gold is said to be very often dissociated from quartz."

Sutcliffe's Mine, North-West of Matlock.—The workings in this mine are on a narrow dyke averaging 4 ft. in width, and dipping to the east at about 80°. The dyke is greatly decomposed to a depth exceeding 300 ft. Some rich patches of nuggety gold were found between 200 ft. and 300 ft. in this mine on the hanging-wall of the dyke. Several nuggets up to 4 or 5 oz. in weight were exhumed from these patches. The gold was mostly free from quartz, and was associated with spongy native copper, azurite, and malachite, limonite, and a greasy micaceous decomposition product of the dyke termed "mutton fat." This material is common in the vadose zone in many mines in dykes, and appears to be a mixture of potash and soda, mica, talc, limonite, kaolin, and free quartz.

Little Comet Mine, Wood's Point.—The dyke worked in this mine is of the narrow type—6 to 10 ft. in width. It is traversed by the usual flat floors of quartz, which in this case are intersected by nearly vertical veins. Rich patches of gold were obtained at and close to the intersections of these veins. One such mass of gold, aggregating in weight more than 80 oz., was discovered in 1913 at a depth of about 220 ft. It was associated with a little quartz and some limonite and malachite. Massive secondary pyrites filled in the interstices between the quartz crystals.

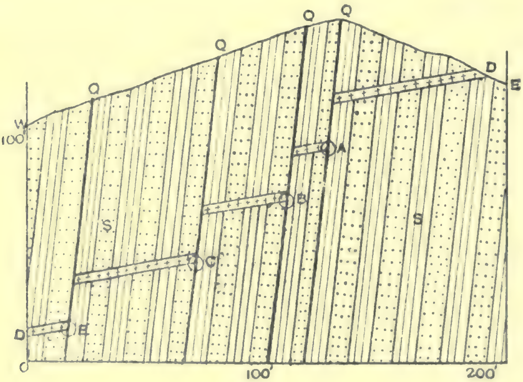

FIG. 9.

SKETCH SECTION OF THE HOME RULE MINE NEAR GAFFNEY'S CREEK.
Showing localization of pockets of gold—A, B, C, E; "Q" = quartz reefs; "D" = lamprophyre dyke; "S" = Silurian slates and sandstones.

Home Rule Mine, near Gaffney's Creek.—The dyke, a narrow one, averaging about 2 ft. in width, dips at an angle of about 20°

to the west, cutting across the strata, which dip here to the west at about 75°. Four step dip-slip faults, in which small laminated quartz-veins have formed, displace the dyke, as in the figure.

The fault-reefs and the veins in the dyke were relatively poor, averaging less than 5 dwt. per ton, but rich patches of gold occurred in the vicinity of the points A, B, C, and D in the figure. The richest values came from pocket " A," which averaged about 30 dwt. to the ton, while the ore from " E " averaged less than 8 dwt. per ton. The greater part of the gold in these patches occurred loose, and not in the quartz. It was associated with limonitized pyrite, native sulphur, and hydrated oxide of iron. The bulk of it was coarse, but some finely-divided flour gold was also present.

Alabama Mine, near Ten-Mile.—The Alabama reef is a narrow bedded laminated reef, normally less than 6 in. in width. At a depth of about 150 ft. from the surface the reef intersects and displaces for a distance of a few feet a lamprophyre dyke, which averages about 6 ft. in width. The Alabama reef at this point dips at an angle of about 80° to the west, and the dyke at between 50° and 60° to the west. At the intersection with the dyke the reef bulges to as much as 4 ft. in width, and rich pockets of gold were found in the quartz in this vicinity. The gold occurred in the form of strings and veinlets through the quartz, and was associated with much red hydrated oxide of iron.

The following tabulated yields from this mine illustrate well the enrichment between 140 ft. and 200 ft. :—

Depth in feet.	Tonnage crushed.	Yield.	
	tons.	oz.	dwt.
0–50	27	72	0
80–90	90½	145	6
120	34½	56	3
140 and 150	208	1172	0
200	279¾	1390	3¼
300	18	51	11

A 1 Mine, Gaffney's Creek.—That an important enrichment occurred in the ore-values in this mine between 100 ft. and 180 ft. from the surface is evident from the following yields, culled from the reports of the mining surveyors and registrars for the period 1862 to 1892 :—

Depth in feet.	Ore Crushed.	Yield
	tons.	oz.
0–50	5652	7747
60–80	7991	10,962
100–130	10,567	20,511
150–180	3871	6626
200	1505	1267
250	120	48

Unfortunately, very little information is now obtainable as to the mode of occurrence of the gold in these upper levels. Mr. J. Friel, manager of the New Loch Fyne mine, Matlock, informed the writer that loose coarse gold, resembling smelted and alluvial gold, was found in vugs in the 60-ft. reef on ledges on the western wall of the dyke, and that films and leaves of gold free from quartz were not uncommon in joint-planes in the dyke from the 300-ft. level of the South A 1 mine.

Morning Star Mine, Wood's Point.—More than £1,000,000 worth of gold has been won from this mine within 400 ft. of the surface. At least 90 % of this gold was unearthed between 1862 and 1875. The early records are incomplete, but as far as they can be interpreted they indicate that the richest quartz came, not from the surface, but from depths between 180 ft. and 350 ft., and particularly about 200 ft., as will be seen from the following figures :—

Date.	Company.	Ore Crushed	Yields.	Depth.
		tons.		ft.
Aug., 1862	—	—	averaging 5 oz. to the ton ..	near surface
Feb., 1864	M'Dermott & Co.	36¾	1619 oz. 4 dwt.	184
April, 1864	Hope	—	4 oz. to the ton	200
June, 1864	Wood's Point Co.	161¾	2632 oz. 4 dwt.	190
June, 1864	Drysdale and Co.	500	7500 oz.	(?) 230
Sept., 1864	Wood's Point Co.	147	2026 oz. 10¼ dwt.	200
Sept., 1864	Drysdale and Co.	300	1500 oz.	(?) 230

The bulk of the gold won from the Morning Star Hill came from two reefs—the Age of Progress, on the west wall of the dyke, and Cherry's reef, on the east wall. Both reefs run out into the Silurian strata, and have proved payable for long distances along the dyke walls. According to Mr. O. A. L. Whitelaw (No. 57, p. 16), the Age of Progress reef was worked along the western wall for 1500 ft., and was poor from the centre of the dyke to the east wall; and Cherry's reef was proved payable for 1100 ft. along the eastern wall, and was poor on the western wall. More than one-third of the total gold won from the Morning Star Hill came from these reefs outside the dyke walls..

Unfortunately, few facts relevant to the mode of occurrence of the gold in these reefs have been preserved. The late Mr. Stacpoole, who was conversant with the early workings in the Morning Star dyke, informed the writer that the gold frequently occurred as strings and veins associated with limonite and "mutton fat," in friable vitreous quartz, and sometimes loose in vugs.

As now seen in the stopes off the Hope adit-level, the Age of Progress reef is, for the most part, vitreous, non-laminated, barren-looking quartz. It is very friable and much iron-stained in places, and is very free from sulphides. Cherry's reef, in the same adit-level, is composed of vitreous quartz, vuggy in places, and much iron-stained. Sulphides are rare or absent, and the dyke near the wall is much decomposed in places.

Between the 300-ft. and 600-ft. levels the present company has intersected several reefs, but up to the present they have yielded little gold. They are, in general, laminated and well mineralized, and the surrounding dyke is hard and little decomposed. The bulk of the gold occurred intimately associated with arsenopyrite along laminations in the quartz and in certain leaders in black slates outside the east wall of the dyke.

It seems very probable, from the available evidence and from the experience of other mines in this belt, that the very rich gold won in the early days from the Morning Star dyke was largely, if not entirely, of secondary origin, and that it was concentrated by long-continued denudation and solution of the gold. The present workings are in the zone of primary values, and such rich yields as of yore cannot be expected. On the other hand, it would be fatuous to claim that the gold is confined to the upper zone of surface decomposition, as every atom of evidence is contrary to this idea.

3.—Black Gold.

Black gold is the miners' term for gold coated with black hydrated oxide of manganese.

Messrs. Selwyn and Ulrich (No. 41, p. 41), speaking of Victorian alluvial gold, say:—

"In some leads—for instance, at Guildford, Daisy Hill, &c.—portion of the gold is commonly coated with black manganese or brown iron ore—'black gold.'"

Such gold was not an uncommon feature in the pre-deep-lead sands and gravels at Ballarat and in the Loddon leads.

Much of the gold from Knowle's and the Georgia dykes at Enoch's Point from shallow depths was of this type. The coating is not always psilomelane, but is often earthy arsenopyrite.

A nugget of black gold, weighing approximately 2 lb. troy, was obtained from the Ball Room chamber in the Eldorado mine, near Gaffney's Creek. Black alluvial gold has also been found in Gaffney's Creek, near Hunt's mine, and near Store Point.

4.—Permanence in Depth.

Until within the last fifteen years prospecting in depth was not encouraged in this belt. The pernicious influence of the theory of Mr. H. A. Thompson (No. 49, p. 246), that the quartz floors in the dykes were filling cracks near the surface, and as such were not likely to penetrate to any great depth, was largely responsible for this state of affairs.

That the mineralization is deep-seated is clear from the evidence brought forward in this paper. Furthermore, conduits must have existed for the conveyance of the auriferous ascending solutions, and the field examination has shown that fault-fissures and orogenic and contraction joints have provided the necessary channels. The recognition of this deep-seated origin of the gold and the initiative displayed by certain companies, such as the A 1 and the Rose of Denmark, in sinking and developing their properties in depth, has acted as an incentive to other companies —*e.g.*, New Loch Fyne and the Morning Star—to prospect their ore-bodies at lower depths, with the result that the New Loch Fyne management has struck a reef, crushings from which of late have averaged about 1 oz. per ton.

The average tenor of the ore from between the 850-ft. and 1000-ft. levels in the A 1 mine has proved richer than any ore previously taken from this mine, with the exception of that obtained from the secondarily enriched zone between 100 and 180 ft. from the surface. Notwithstanding the fact that a considerable amount of mullock was crushed with the quartz, 48,961 tons of it yielded 47,398 ozs. of gold during the years 1913 to 1918 inclusive. Almost the whole of this ore came from between 800 and 1000 ft.

Again, the quartz from the Rose of Denmark mine was relatively poor, averaging about 7 dwt., from the surface down to the main adit-level, a depth of at least 500 ft. at the engine chamber. Below this level the ore became richer, and about 40,000 tons of quartz, averaging about 11 dwt. of gold per ton, were crushed between the main adit-level and No. 5 below it.

It seems reasonable to expect that many other mines in this belt will, if developed in depth, show the same general result.

However, secondary enrichment has had a marked effect on the auriferous values of many of the quartz reefs, and its bearing on the tenor of the ore in depth must not be overlooked. Mines like the Royal Standard, Morning Star, Eldorado, New Loch Fyne, Leichhardt, &c., are not likely to prove as rich in depth as near the surface, owing to the extensive secondary concentration of the gold in their upper zones.

5.—Suggestions for Future Mining, &c.

The assets of this belt for mining purposes are a good climate, plenty of timber for fuel and timbering, and, normally, a sufficient supply of water. The writer is of the opinion that much more use could be made of the Goulburn River and its tributaries for the generation of electrical and other power, and also for sluicing those vast high-level and other gravel deposits that have been so little worked.

The disadvantages with which the mines in this belt have to contend are as follows:—A youthful topography; absence of railways; bad roads; and the concomitant inflated costs of mining machinery, stores and provisions, and the difficulty of getting skilled labour.

For future mining to be a success, sound business methods and scientific development will have to be employed. The policy of the past, of picking the eyes out of the mines and disbursing every penny in dividends without a thought for the morrow, must not be tolerated.

Furthermore, development of this belt will not be possible until the economics of the gold question have been solved and the policy of our Government towards gold-mining has been defined. At present whole-hearted judicious Government support seems to be the only means of saving the industry. The present policy of expending an amount of some £10,000 to £20,000 annually to encourage mining in the State is absolutely futile, and defeats its own object.

The possibility of the discovery of new goldfields in this belt seems a remote one. Nature has been kind to the prospector in removing the overburden of the reefs, and, although the topography is wild and juvenile, prospecting, on the whole, has been very thorough. All the more important reefs were discovered prior to 1870, and finds since then have, with few exceptions, yielded little gold.

The possibility of reefs which are barren or poor at the surface becoming payable or rich in depth owing to the complete solution of the gold from near the surface in descending waters must not be overlooked, and no mine can be condemned as a "dud" concern until it has been tested below the base of the zone of surface decomposition. Many mines in this belt have not been prospected in the primary sulphide zone, and consequently their worth or otherwise has not been proven. Further, many reefs have not been thoroughly explored and developed near the surface —*e.g.*, Unknown, Royal Standard, Eldorado, Little Comet, &c.

Although boring is not of much value for sampling reefs, it is useful in locating new ones, particularly in dyke formations. It is relatively cheap, and could be applied with justification in certain places in this belt—*e.g.*, Royal Standard mine, where considerably more than £50,000 worth of gold was won from within 100 ft. of the surface, and no reefs have been located at lower levels.

The tribute system should be encouraged. Numerous instances could be quoted of tributing parties locating new reefs and shoots of gold, which often have given new lease of life to abandoned and struggling mines.

It is a widely-accepted belief among miners in this belt that the vicinity of the walls of the dykes are the favourite places for finding gold. This theory is in keeping with the facts of the gold-occurrence in the vadose zone, and is readily explained, as the walls of the dykes have afforded the easiest channels for surface descending auriferous solutions, but caution should be exercised in applying the theory generally, as it has not been demonstrated that the gold-occurrence in the primary zone conforms to it.

The petrologist can be of some assistance to the miner in that he can determine whether any particular dyke is likely to be auriferous or not. The results of the present investigation indicate that payably-auriferous reefs are confined to dykes of dioritic and gabbroidal composition in this belt, and that the more acid and more basic ones are either non-auriferous or poorly so.

In conclusion, the following tried mines are regarded as the ones most worthy of further attention, viz.:—Unknown, All Nations, Star of the West, Gleeson's and Sailor Bill's, Royal Standard, and Eldorado. The Unknown mine was rich near the surface, averaging more than an ounce to the ton to a depth of 150 ft. Below this level it remains almost untested. Gold can be seen even now in specimens picked from the surface outcrop and shallow workings on the reef.

The All Nations, from which approximately 132,000 oz. of gold were unearthed, was a very promising reef near the surface, and at one time was regarded by the District Mining Surveyor as a better proposition than the Morning Star. No systematic work has been done to test it below a depth of 400 ft. from the surface.

6.—NOTES ON THE ORIGIN OF NUGGETS.

Accepting as a postulate that the nuggets found in the alluvial in Victoria were shed from quartz-veins—a belief the evidence in support of which is overwhelming—what, then, has been the cause of the aggregation of such large masses of gold in the veins? Current explanation invokes the aid of an indicator—a term somewhat loosely applied to thin bedded pyritic, chloritic, and carbonaceous seams, laminated iron-stained quartz-veins, narrow fissures or fractures, and "pug seams." Where these indicators intersect a more or less flat vein of quartz, nuggety gold is the rule.

In the only area in the region described in this paper from which many nuggets have been unearthed from the alluvial—namely, Enoch's Point—nuggets have been shown to occur in such a manner in certain dykes—*e.g.*, Knowle's and the Georgia—as to leave no doubt whatever as to their deposition from secondary surface-descending auriferous solutions at points where the descent of these waters has been impeded. Furthermore, the secondary origin of the May Moon dyke nuggets and those from Sutcliffe's and the Little Comet mines is undoubted.

It is believed that many, if not most, of the nuggets found in quartz reefs and alluvial deposits in Victoria have originated in a similar manner, and in the following pages evidence will be brought forward in support of this theory.

With the exception of the Ballarat East goldfield, the nuggets found in quartz reefs in Victoria have, in practically all cases, come from depths less than 400 ft. or 450 ft. from the surface. At Kingower, Wedderburn, Dunolly, Moliagul, Rheola, and Maryborough—fields notorious for the size and number of the alluvial nuggets—rich nuggety gold has been extracted from many of the quartz-veins within 300 ft. from the surface; but below this depth payable reefs are exceptional, and nuggets are unknown.

Messrs. Selwyn and Ulrich (No. 41, p. 41), in dealing with the mode of occurrence of gold in Victoria, state that

> "It is found by practical experience that the gold at and near the surface is coarser . . . than in depth, and, although exceptions are known, it is by most quartz miners acknowledged, so to speak, as a rule that the gold becomes finer and finer and more intimately mixed with the quartz and pyrites the deeper the reefs are worked."

At Ballarat East we have an exception to this rule, for nuggets have been won from depths as great as 1300 ft. from the surface. However, this field is intensely fractured and faulted, and such minerals as kaolin and radial marcasite, which are generally acknowledged to be formed by surface descending waters, were not uncommon in the reefs in certain mines—*e.g.*, North Woah Hawp—at depths as great as 1200 ft. A study of the paragenetic relations of the vein-minerals shows that in all cases the gold was the last mineral introduced into the reefs. Furthermore, the way the gold occurs deposited on the sulphide minerals sphalerite and galena, and less commonly pyrite and pyrrhotite, and filling fractures in friable quartz, suggests a secondary origin for it.

Professor Gregory (No. 18, p. 44) says:—

> "Many facts suggest that most of the gold in the Ballarat East goldfields has reached its present position by the action of solutions descending from above,"

and gives evidence in support of this contention. The writer thinks the facts warrant the conclusion that the bulk of the gold of the Ballarat East field is of secondary origin, and that it was probably deposited from descending waters. The indicators apparently provided the necessary precipitants for the gold in solutions crossing them.

On certain other fields, as will be seen from the following examples, the indicators apparently were channels along which auriferous solutions circulated. At Wedderburn the indicator is usually a thin bedded iron-stained quartz-vein within beds of carbonaceous slate. In his report on this area (No. 56, p. 13), Mr. O. A. L. Whitelaw says :—

"I have not noticed one instance of an indicator producing rich pockets of gold where this metasomatic quartz is absent."

He, furthermore, claims that the gold-bearing solutions circulated along the fault-planes and in the indicators themselves, and quotes analyses showing that the indicators are always auriferous.

According to Mr. R. A. F. Murray (No. 36, p. 5), at Paddy's Gully, Rokewood Junction, a drive along a reef at between 20 and 30 ft. from the surface showed a narrow, soft, slaty band, sometimes ferruginous, sometimes soft and clayey, varying from brown or grey to nearly black in colour, in contact with the hanging wall of the reef. This band is claimed by Mr. Murray to be an indicator, and, according to him,

"An inch or two of the stone in contact with the slate band is of friable character, and in this lies the gold, in places stated to be in the form of an almost solid vein, in pieces up to several ounces in weight. The rest of the reef is of the character known as 'buck,' or stone of a hard, glassy, unpromising character."

This example, in the writer's opinion, is very significant of a secondary origin for the gold from descending waters.

According to Mr. W. Bradford (No. 6), the indicator in the Pyrenees goldfields is often a thin bedded ferruginous quartz-vein, which sometimes carries free gold.

At Moliagul and Rheola the indicators are sometimes thin ferruginous quartz-veins and fissures filled with soft clay or pug. Finely-divided "flour" gold is not uncommon in these indicators.

In other cases cross-veins and faults appear to have provided the conduits for the auriferous solutions, and the nuggety gold occurs in the vicinity of some pyritic or carbonaceous precipitant. At Maryborough, for instance, the indicator is usually a thin bedded, laminated quartz-vein within a bed of green or purple pyritic slate. According to Mr. A. M. Howitt (No. 24, p. 15), gold never occurs in the indicators. He says :—

"In some cases the gold shoot is at the junction of the cross-vein with the laminated quartz-vein in the indicator, but this happens only when secondary pyrites is disseminated in the laminated vein, as at Inkerman and Alma. In other cases, as at Waterloo, the rich gold shoot is just to one side of the laminated quartz-vein, and opposite a decomposed pyritic seam."

And further—

"In every case noted of enrichment along the indicator, pyrites was present under one or other of these conditions."

The cross-veins were usually narrow and very ferruginous. According to Mr. Howitt, round, shotty gold, generally partly coated with oxide of iron and in some cases resembling water-worn gold, is found in some of these veins at or close to their intersections with the indicators.

From within a few yards of the outcrop of the Matrix reef, near Rheola, nuggets of 810 oz., 805 oz., and 782 oz., and one of 59 lb. weight, were exhumed. Several patches of nuggety gold have been obtained from the reef itself. Mr. H. S. Whitelaw (No. 54, p. 32) claims that

"The gold patches occur only where a thin cross-vein of quartz, 2 in. to 12 in. thick, intersects a lead-coloured slate in the immediate vicinity of a fault."

From one of these pockets, at a depth of less than 100 ft. from the surface, 258 oz. of gold were taken out of a space of 1 cub. ft. The quartz carrying the gold is highly ferruginous.

The structure of many alluvial nuggets lends support to the theory that they were deposited from surface-descending auriferous waters.

Several Victorian alluvial nuggets examined by Prof. A. Liversidge (No. 32, p. 260) enclosed considerable amounts of ferric-hydroxide, although in many cases they were apparently not porous, and the hydroxide of iron was not visible at the surface. The Latrobe nugget, 40 oz. in weight, from the M'Ivor goldfield, is a mass of reticulating crystals of gold. The writer believes that this nugget is now preserved in the Natural History Museum, in London. Flat nuggets with approximately parallel sides were not uncommon in the alluvial. Nuggets of this type of secondary origin have been described in the present paper from the Georgia mine, near Enoch's Point. Professor A. Liversidge also described a flat nugget from Gippsland, which, according to him, appears to have been formed in a narrow fissure.

Again, the nuggety gold found in our quartz reefs is invariably of good quality, and rarely is of less fineness than 950. The indicator gold of the Ballarat East goldfield was notorious for its purity—999.5, according to Professor Gregory (No. 18, p. 44) —and that from Wedderburn, Moliagul, and Maryborough was of greater average fineness than 950. At the last-named place the indicator reef gold was always purer than the normal reef gold not associated with indicators. Furthermore, Dr. Don's comprehensive analyses of the gold obtained near the surface and from depth at Ballarat and Walhalla, in Victoria, and from other Australasian goldfields, indicate that

"On the whole the average fineness of the gold in the vadose zone is appreciably greater than in the deeper circulation in the same district" (No. 10, pp. 607, 608).

This refining of the gold in the vadose zone, of course, may have taken place after its deposition, but, considered in conjunction with the mode of occurrence, mineral associations, and the character of the gold, it seems more probable that it was deposited in the refined form.

In conclusion, the writer is of the opinion that the abovementioned data strongly support the theory that most nuggets in reefs, and consequently those found in the alluvial in Victoria, have been deposited from secondary descending vadose solutions.

PART IV.—GENERAL SUMMARY, &c.

1.—General Summary.

Highly folded marine sediments of Silurian and Ordovician age form the bed-rocks of the Walhalla–Wood's Point belt. Silurian beds cover the whole of the central geosynclinal area of the belt, while the Ordovician strata appear at the flanks in the cores of domed geanticlinal inliers.

The uppermost beds of the Silurian—the Walhalla beds—are of shallow water marine or estuarine origin, and consist lithologically of grits and conglomerates, with intercalated coral and crinoidal limestones, feldspathic sandstones, and thin bedded black shales. Their fossil contents show that their stratigraphic position is very high in the Silurian series.

The Panenka and Monograptus beds are rich in fossils, and appear to be of deeper water origin. The Store Point–Mount Useful beds are, in the absence of fossil remains, provisionally included with the Silurian beds.

The Ordovician beds consist for the most part of highly-cleaved black slates rich in graptolite remains.

The main folding of these sediments occurred in Devonian (?) times, and was accompanied by extensive faulting and vulcanicity and the formation of the auriferous quartz-veins. The average trend of the sediments is N.N.W. They bend round the Baw-Baw granodiorite massif, the intrusion of which has probably caused this curvature.

As a concomitant of the folding and faulting came the intrusion of the dyke rocks of this belt. These dykes follow closely the strike of the sediments, and are most abundant in the central geosynclinal area. Normally, the dykes are narrow, but occasionally they expand into elliptical intrusions as much as 300 ft. wide. They form a petrographic province in which the following rock-types are represented:—Granophyres, aplites, quartz feldspar porphyries, diorite porphyrites, lamprophyres, gabbro porphyrites, basalt, hornblende–pyroxene rocks, hornblendites, and peridotite. That these dykes are consanguineous is proved by the remarkable similarity in their petrological characters, structural features, and metasomatic alteration. Their age is apparently Devonian, as they are overlain by the Lower Carboniferous beds near Mansfield, and are intrusive into the uppermost beds of the Silurian.

The petrology of these dyke rocks has been discussed at some length—firstly, because some of them are new types to Victoria; secondly, because no detailed description of them has been attempted previously; and thirdly, because the nature of the metasomatic alteration undergone by them is so interesting and economically important.

Not one specimen collected in the field was free from metasomatic alteration. The following types of alteration are recognizable:—

1. Regional alteration, before the intrusions had cooled sufficiently to fracture, by mineralizers released from the magma. There appear to be two stages in this alteration—

   (*a*) A late magmatic stage characterized by the development of interstitial quartz albite, orthoclase, and micropegmatite. The actinolitic and tremolitic outgrowths to the hornblende crystals are probably formed at this time.

   (*b*) Propylitization characterized by the formation of abundant chlorite and leucoxene, and some massive carbonate, pyrite, and pyrrhotite and occasional epidote and zoisite.

2. Hydrothermal alteration of the wall-rocks adjoining the veins. The effect of the vein-solutions on the wall-rocks has been intensely destructive. All the minerals of the propylitic *facies*, with the exception of apatite and some of the quartz, have succumbed to the action of the vein-solutions, and have been replaced by ubiquitous dusty carbonates, flakes of sericite, and some albite, pyrite, and leucoxene. Chemically, the percentages of CO_2 and K_2O have been markedly increased and Na_2O and H_2O greatly reduced, and SiO_2, Al_2O_3, TiO_2, and FeO have been partially leached.

Many of the reefs within the narrow dykes appear to be filling contraction joints. In the dyke expansions the parallelism of the reefs with the joint-systems of the dykes and their prismatic arrangement suggest that the original jointing was determined by the contraction of the dykes during cooling. Movement has occurred along these joint-planes in many instances prior to the introduction of the quartz—*e.g.*, in the Morning Star and New Loch Fyne dykes.

On the other hand, many reefs within and associated with dykes occur in faults which are quite independent of contraction jointing.

Evidence is presented to show that some reefs have been enlarged by replacement of the wall-rock surrounding cracks or joints, and that in other cases they are simply fissure-fillings. A combination of replacement and deposition from solution in fissures is usual in most reefs.

The various theories usually propounded to explain the genesis of the gold in the quartz-veins have been examined, and the only one that harmonizes with the facts is the theory that the gold came from magmatic sources.

The lean copper ores in certain basic and ultra-basic rocks were probably introduced during the propylitic phase of alteration.

Arsenopyrite, bournonite, pyrite, sphalerite, tetrahedrite, and galena are the most prevalent sulphide minerals in the veins. Quartz and carbonates are the usual gangue minerals, but albite and sericite are sometimes present. Quartz, carbonates, albite, pyrite, sphalerite, galena, and sometimes arsenopyrite, antedate the deposition of the gold ; the latter mineral is often intimately admixed with bournonite and tetrahedrite, and sometimes with arsenopyrite.

Structural features are believed to be far more important than stratigraphical zones in causing the localization of the gold. Payably auriferous reefs are found in or associated only with dykes of dioritic and gabbroidal composition.

The main deposition of primary gold appears to have been determined by precipitation of the gold in the ascending auriferous solutions by the previously-formed sulphide minerals—pyrite, sphalerite, galena, and arsenopyrite—and by carbonaceous and other rock-residues and occasionally by the vein carbonates.

Secondary processes — denudation, gravity, solution, and precipitation—have re-concentrated the primary gold, forming important shoots and pockets of gold within the vadose zone.

Many mines in this belt were very rich near the surface, but failed to maintain their values in depth. Such enrichment is believed to be due to the mechanical concentration in situ of the gold released from the former upward extensions of the reefs.

In numerous other instances marked enrichment occurred in the auriferous values within and near the base of the vadose zone. The mode of occurrence and the character of the gold from the enriched shoots and pockets in the lower part of the vadose zone show conclusively that it was deposited from descending solutions.

The walls of the dykes have often afforded the readiest conduits for these waters, and much of the gold has been deposited at points where structural features—*e.g.*, ledges, faults, cross-veins, &c.—have checked their descent.

In several mines nuggets of gold have been found on the dyke walls in such a manner as to leave no doubt whatever as to their origin from surface descending auriferous waters. It is contended that most gold nuggets in Victoria have been formed in a similar manner, and evidence is adduced in support of this theory.

Although secondary processes have caused considerable enrichment in the vadose zone, all the available evidence supports the belief that the gold values persist in depth. Mines like the Morning Star, New Loch Fyne, Royal Standard, and Eldorado are not likely to prove as rich in depth as near the surface, but there is no justification for the theory that the reefs in these veins will be unpayable within the primary zone.

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EXPLANATION OF PLATE I. (MAP).

Geological and Locality Map of the Walhalla-Wood's Point auriferous belt, constructed mainly from the survey maps of Messrs. W. Baragwanath and O. A. L. Whitelaw. The Upper Ordovician beds near Enoch's Point are not shown. The map shows clearly the localisation of the dykes and chief mines between the eastern and western basal grits of the Walhalla beds of Upper Silurian age.

EXPLANATION OF PLATES II. TO VII. (MICROPHOTOGRAPHS).

FIG. 1.—Aplite vein in Eureka dyke, near Walhalla, × 13 polarized light, showing stunted prisms of albite in a quartz base, laths of biotite, black needles of ilmenite, and speckled aggregates of sericite after feldspar.

FIG. 2.—Granophyre, Alabama dyke, near Matlock, × 20 polarized light, showing fine intergrowth of quartz and feldspar surrounding a large plagioclase crystal.

FIG. 3.—Sericitized quartz feldspar porphyry, Brohan's Reef, near Aberfeldy, × 15 polarized light, showing a rounded phenocryst of quartz, an irregular-shaped sericitized phenocryst of feldspar, and a large black crystal of pyrite having a fringe of secondary quartz.

FIG. 4.—Diorite porphyrite, Hope adit level, Morning Star dyke, showing phenocrysts of hornblende, including ilmenite, flakes of biotite, prisms of altered feldspar, and a micrographic intergrowth of quartz and feldspar.

FIG. 5.—Specimen No. 229, gabbro porphyrite, Coronation mine, Tubal Cain dyke, × 6 O.L., showing phenocrysts of augite, biotite, and plagioclase and black grains of ilmenite.

FIG. 6.—Specimen No. 214, porphyritic basalt, lower adit level, Coronation mine, Tubal Cain dyke, × 6 O.L., showing porphyritic phenocrysts of titaniferous augite veined by chlorite, in a fine-grained ground-mass.

FIG. 7.—Specimen No. 178, hornblende pyroxene dyke rock (perknite), 1 mile east of Toombon, × 16 O.L., showing fibrous actinolitic outgrowths to hornblende and inclusions of colourless monoclinic augite.

FIG. 8.—Hornblende pyroxene rock (perknite), Kelly's dyke, near Walhalla, × 16 O.L., showing micropœcilitic inclusions of colourless augite in hornblende.

FIG. 9.—Hornblende peridotite, near Aberfeldy, × 16 O.L., showing concentric and internal alteration of olivine.

FIG. 10.—Granophyre, Alabama dyke, near Matlock, showing a pseudomorph of chlorite and carbonate after an idiomorphic hornblende crystal. Leucoxene (black) has been partly concentrated towards the margin of the hornblende.

FIG. 11.—New Loch Fyne dyke, No. 5 adit level, north-west edge, × 27 O.L., showing the veining and replacing of a hornblende crystal by chlorite and carbonates.

Photos by the author unless otherwise indicated

FIG. 12.—New Loch Fyne dyke, north-west edge of intrusion, No. 5 adit level, × 23 polarized light, showing the veining and replacing of a feldspar phenocryst by chlorite (pennine) along parallel lines. The black hexagonal inclusion is apatite.

FIG. 13.—Specimen No. 99, granophyre, Alabama dyke, near Matlock, × 15 O.L., showing radiating and stellate epidote and zoisite.

FIG. 14.—Intensely altered (carbonated) basic New Loch Fyne dyke, No. 5 adit level, × 17 O.L., showing "sagenitic" webs of rutile after biotite. Photo. by G. Sweeting, Esq.

FIG. 15.—Vein-altered lamprophyre dyke, Kelly's Hill mine, near Matlock, × 18 O.L., showing an epimorph of pyrite (black) on a crystal of leucoxene which replaces ilmenite.

FIG. 16.—Hydrothermally-altered Rose of Denmark dyke (hornblende lamprophyre), near a quartz-vein, × 15 O.L., showing idiomorphic crystals of pyrite and arsenopyrite in the sericitized and carbonated rock. A veinlet of quartz intersects a pyrite crystal.

FIG. 17.—Specimen No. 223, quartz-epidote-carbonate vein in basalt, Coronation mine, Tubal Cain dyke, × 16 O.L.

FIG. 18.—Copper-bearing New Loch Fyne dyke, No. 5 adit level, × 25 O.L., showing corrosion of biotite by chalcopyrite. The ring of light-coloured mineral between the chalcopyrite and biotite is carbonate.

FIG. 19.—Specimen No. J11*a*, auriferous quartz, No. 9 intermediate level, A 1 mine, × 15 O.L., showing the replacement-origin of the quartz. Skeletons of slate and sandstone are seen almost entirely replaced by granular quartz and dusty and granular pyrite.

FIG. 20.—Specimen No. J10, quartz-vein from stopes above No. 6 level, Rose of Denmark mine, × 19, crossed nicols, showing pellucid crystals of albite associated with quartz and ankerite.

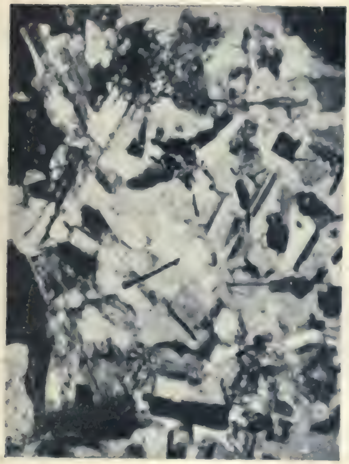
FIG. 21.—Gold in ankerite, stopes above 220-ft. level, Little Comet mine, × 19 O.L., showing gold (black) encrusting and veining the ankerite.

FIG 22.—Auriferous quartz from No. 8 level, A 1 mine, × 17 reflected light, showing the intimate association of the light-coloured gold ("G") and the black bournonite ("B") and their subsequent origin to the idiomorphic quartz-crystals on which they are moulded.

FIG. 23.—Auriferous quartz, 850-ft. level, A 1 mine, × 9 reflected light, showing the relationship between sphalerite ("S") and bournonite ("B"). Photo. by H. Smith, Royal School of Mines, London.

FIG. 24.—Specimen No. 11*a*, No. 9 intermediate level, A 1 mine, × 17 O.L., showing idiomorphic quartz-crystals included in bournonite (black). A little gold is admixed with the bournonite.

Photos by the author unless otherwise indicated.



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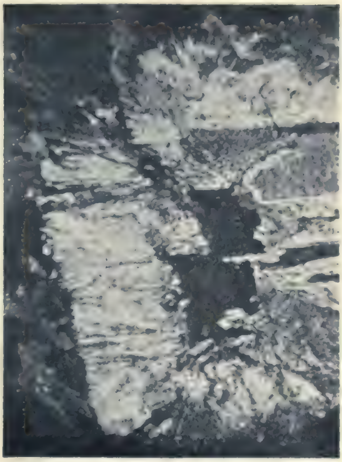

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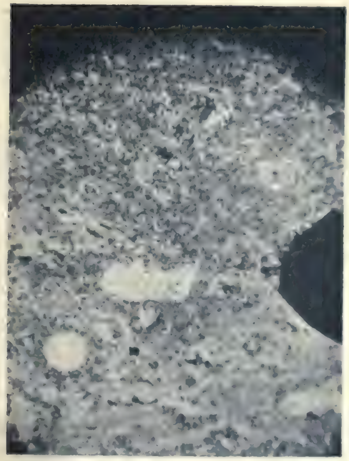

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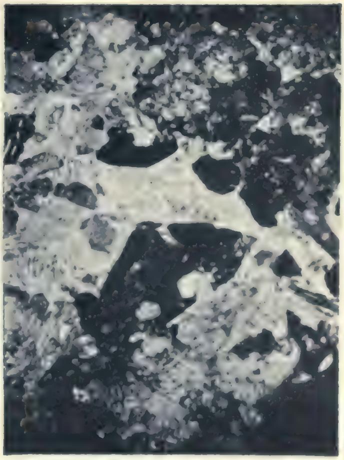

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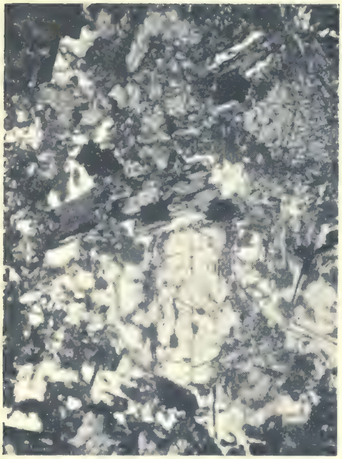

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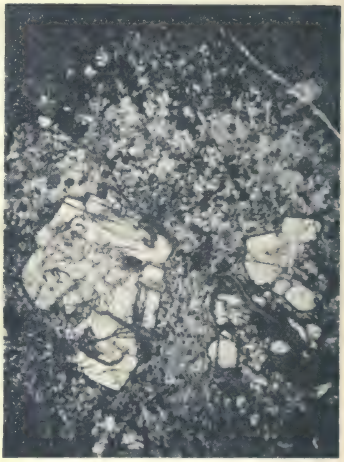

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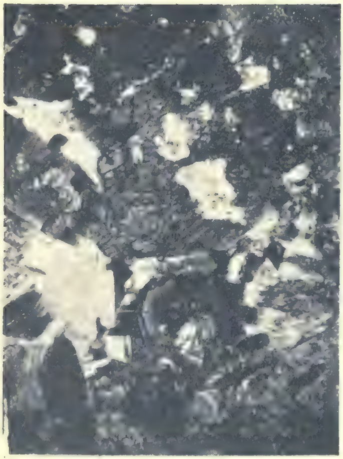

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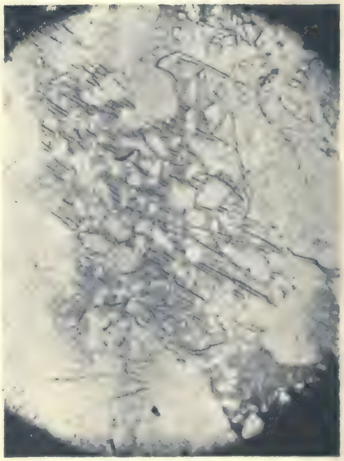

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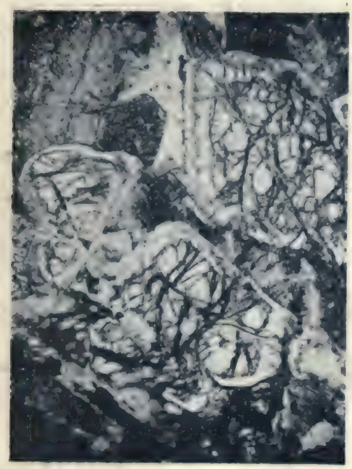

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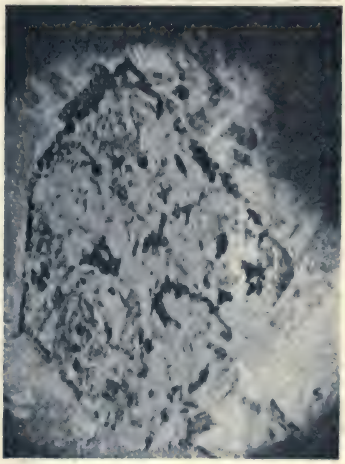

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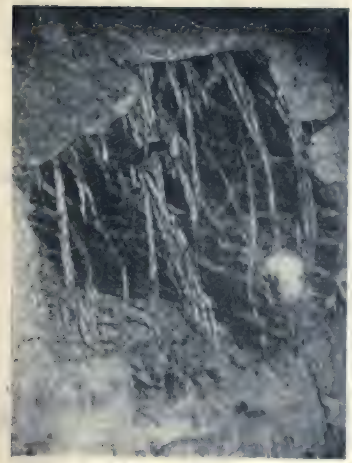

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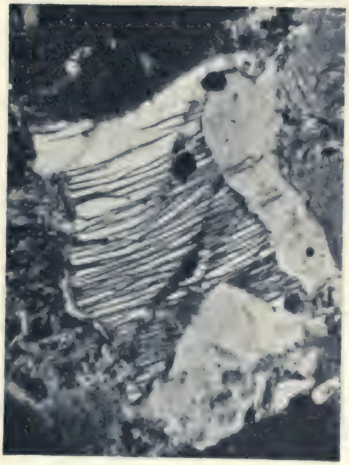

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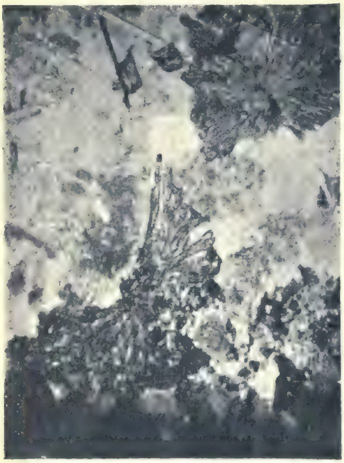

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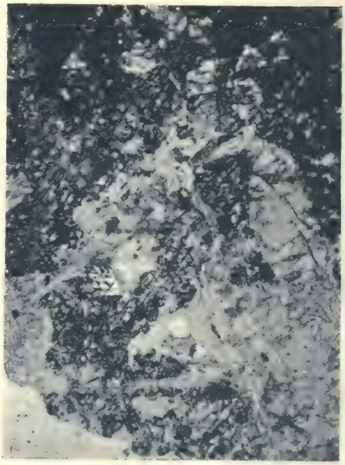

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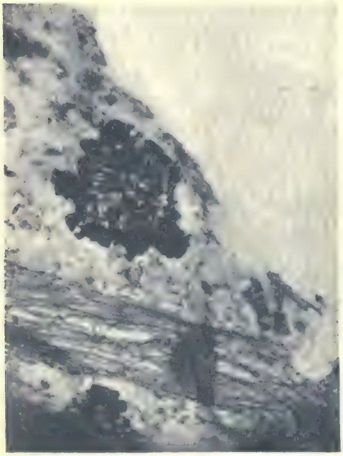

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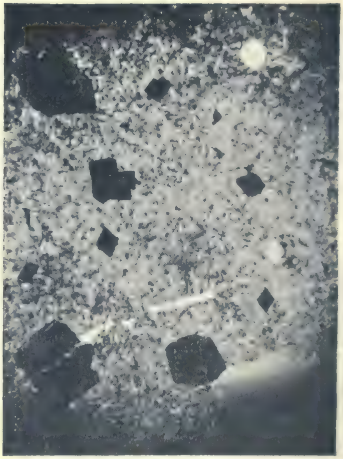

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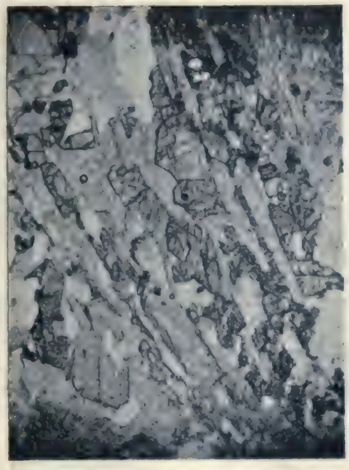

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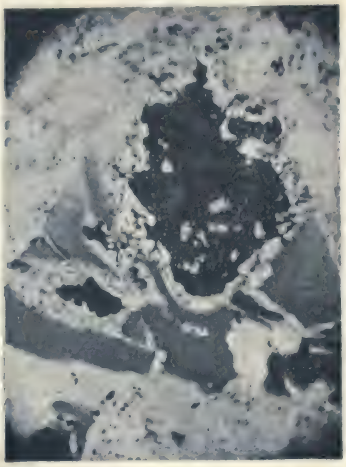
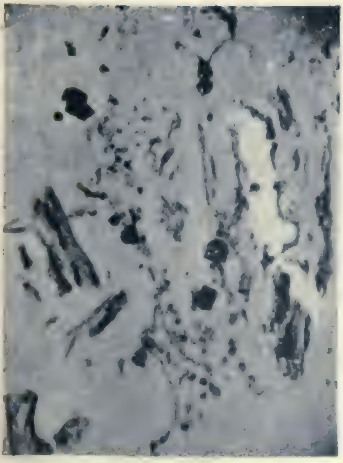


FIG. 18.



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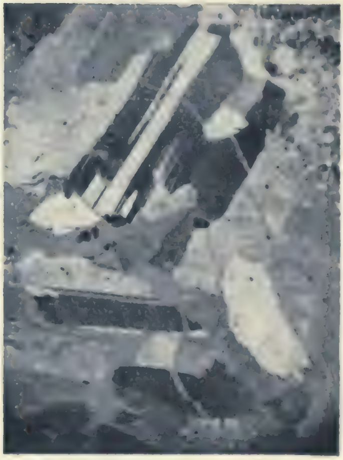
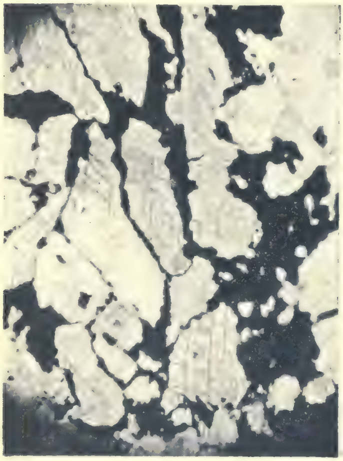


FIG. 20.

PLATE VII. JUNNER—ON WALHALLA-WOOD'S POINT AURIFEROUS BELT.



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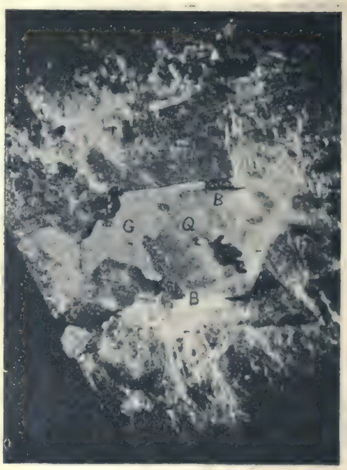

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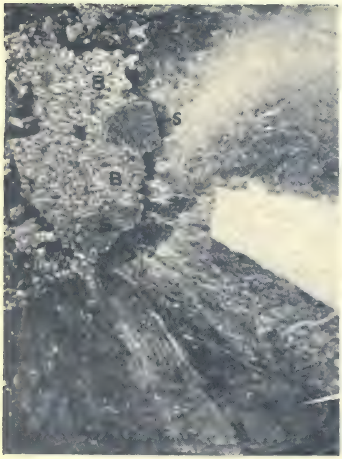

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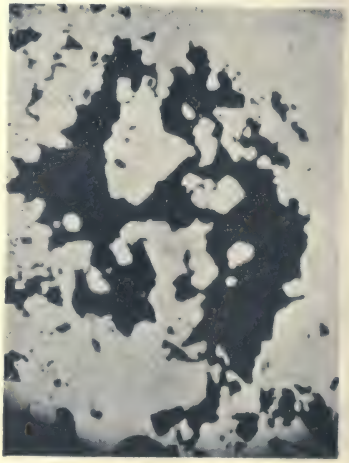

FIG. 24.

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